Bachelor's Degree Final Project

BACHELOR'S DEGREE IN INDUSTRIAL TECHNOLOGY ENGINEERING

ASSEMBLING OF FURNITURE WITHOUT SCREWS

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1. Summary

The present study develops a model that facilitates the assembly of a piece of furniture. This project is born with the idea of simplifying the assembly of IKEA furniture, where the user buys one that has to be assembled from boards and screws among other elements that are provided.

The starting point of this project is a previous one in which specific unions were designed and studied in depth to simplify the assembly of any furniture. In this project one of the unions in particular will be studied, trying to solve all the unions of a specific piece of furniture with it. A series of elements / complements will also be proposed based on this same concept of the non-use of screws.

First of all the state of the art is made, to see what does already exist and see which are the strengths and limitations of the products. Based on these, you will find out what attributes you want the new product to have to obtain a better solution, combining the best features of the different designs found.

On the other hand, users are analyzed in order to understand the needs of the market and cover them with a series of functions, which mark the different conditions that the design must fulfill in order to achieve the objectives proposed.

Based on these two analysis, the guidelines of the project are defined in order to define the geometry and properties that the design element must meet in order to find an improved product.

Once the objectives and function of the design object have been defined, the project is carried out through all the design stages.

A section is dedicated to study the elements required in the assembly of the furniture, as well as a thorough study of the possible materials to be used.

Finally, once a solution that meets the requirements of the project is found, a study is done on the economic cost of this solution in order to see if it’s economically doable. Creating with all this a project with possibilities to be launched into the market and be used based on what explained in this project.

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2. Preface

2.1 Origin of the project

This work is born as a natural continuation of a previous project consisting on the design of an item that served, as a substitute for screws, to build a piece of furniture based on the idea of doing it yourself (DIY). The idea is to take the previous designs, choose one and study it thoroughly.

Nowadays there is a need to facilitate the assembly of furniture with DIY, or to give simple instructions to all furnishings, which are accompanied by all the necessary equipment to do so.

It is clear that today there are many offers of furniture available to be built from home. The truth is that what seems to be very easy is, apparently, something difficult. In addition, these services often involve the use of screws, nails, scribbles, etc, which obviously complicate the assembly.

It also appears to be common that people design their own furniture from home. Even those eventually hire someone to complete the assembly.

This project should optimize the previous design and try to solve all the joints of a piece of furniture with the same item. It will also include a study of the manufacturing process. With this project, the user can really get involved in producing the furniture in question.

2.2 Pre-requirements

A first requirement is to create a product that anyone with any knowledge can realize. If someday this project is launched into the market, one could be able to download the files designed from an online platform and make itself a furniture.

Another requirement for this project is to propose a solution that does not need screws. That is, the unions designed will work as substitutes of the function of screws.

2.3 Motivation

The main motivation of this project was to design something innovative, emerging and with potential future. Innovative and emerging because the concept of DIY is relatively new, and because it is becoming more and more known. And with a potential future because it is believed that this concept in the near future will be commonly used.

The project is presented as a challenge as it involves several problems. Three-dimensional design, structural analysis, the production process and even budget planning.

The fact that we work in technology companies facilitates resources in order to meet the goals of the project.

3. Introduction

3.1 Objectives of the project

The main goal of the project consists on the design and evaluation of a few modules that allow building a piece of the furniture without the need of screws.

This system aims to enable the installation of a very common piece of furniture; a Bookshelf. To make it possible and so that it is able to compete in today's market, it must be produced at a competitive price.

As well, some applications will be proposed for the furniture, using the same concept of non-screw connections.

The design must have easy access so that the user could download it from a main page, making it DIY (do it yourself).

In order to achieve the main goal, being so to verify the modules to build the shelf, the following points will be worked through:

1. Easy building
2. Minimizing final cost
3. Manufacturing process and DIY
4. Sustainable, reciclable or biodegradable materials
5. Achieve a design that can have sliding doors, shelves, hangers and other accessories.

3.2 Scope of the project

Will take into account the most relevant points of a real project. From an initial study of the State of the art and the market and its needs, through the calculation and design of the elements to the assembly of a bookshelf. As well as the cost study of the project to see if the solution proposed is economically viable.

The joints designed only will be applicable for domestic furniture of average size.

On the other hand, this project is not a Business Plan, but will provide data related to the possible strategy of marketing.

Finally a study of the possible materials is made, but it is clear that the material used is just a proposal that can support alternatives. Is not necessarily a final proposal.

3.3 Project limitations

In the moment a project starts, it is as important to know the objectives and scope as it is to understand their restrictions and limitations. This way, you can have an overview of at what point is the proposal and know the limitations form which the project starts. The limitations of this project are the following:

- No study has been done of alternative processes by which we could manufacture the design element of this project.
- Even though the study is focused on solving the unions of a particular shelf, no study has been done on how to apply the modules to a piece of furniture with other dimensions.
- The product designed is supposed to be in its useful life working with wooden planks. In this project we study the properties and characteristics that the item must have in order to fulfil its function, it assembling furniture without screws, but there is no study on which is the ideal material for this element designed.
- The loss of quality due to the fact of printing the union modules with 3D Technology has not been taken into account in the development of this project.
- Due to calculation limitations, no simulation has been done of the whole furniture built. Only local simulations have been done.

- When optimizing the module in I, no simulation has been done considering the possibility of a Horizontal force, that could possibly affect the furniture's stability.
- When designing the complementary elements for the furniture, no optimisation of the blocks in the union modules has been done.
- No Go-To Market study or Business Plan has been done in order to launch into the market the proposed product.

4. Previous study

4.1. Market study: state of art

Below, we will briefly describe some similar models that are currently on the market:

Design 1:

Name: Tap table

Designer/Brand: Desconegut

Material/Fabrication process: Plastic, 3D print.

Price: Unknown

Description: This design is used to mount a table. The pieces indicated in blue are the components printed in 3D and in white the material used for the table (in this case wood). It is a simple design and easy to assemble. It has a component to be able to join the legs with the platform of the table and other component to hold the legs.

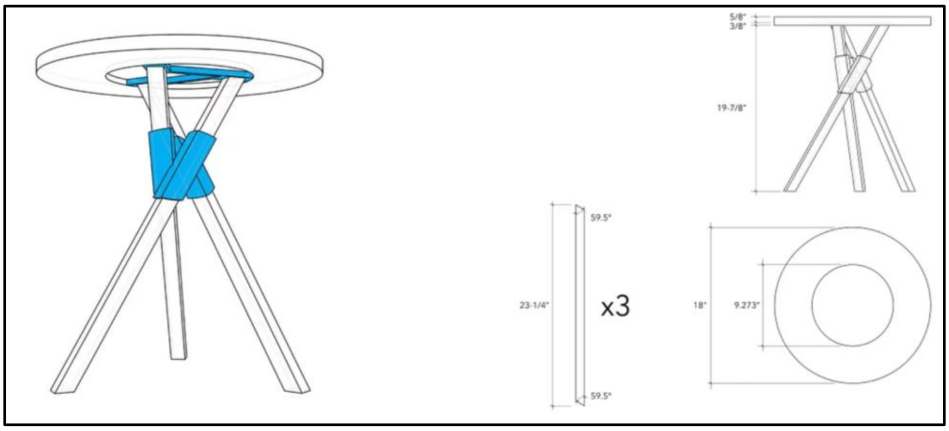


Image 1: Design 1 - State of art

Possible improvements:

-To be more creative, when it comes to mounting shelves, or other furniture, add more "entries" of planks, that is, not only can they fit two or three planks per piece but also offer them with 4 board entrances to be able to make the shelf large, gaining rows and columns, according to the designer of the shelf.

-Biodegradable material. A possible improvement in the face of a sustainable and environmentally-friendly product would be to be able to make this product with a plastic, or other material, that is degraded with ease by ending its useful life, whenever possible to continue fulfilling its function and maintaining its necessary properties to do this.

Design 2:

Name: 3D Printed Wood Joinery

Designer/Brand: Studio Minale-Maeda

Material/Fabrication process: Plastic, 3D print

Price: Unknown

Description: These components serve to attach the legs to a table. As we can see, its design is complex but does not need other fastenings to keep up. The piece makes a union between the legs of the table.

Image 2: Design 2 - State of art

Possible improvements:

-Offer more diversity of ways to assemble furniture from different geometries, that the angles of opening of the pieces are not the same angle.

-To be more creative, when it comes to mounting shelves, or other furniture, add more "entries" of planks, that is, not only can they fit two or three planks per piece but also offer them with 4 board entrances to be able to make the shelf large, gaining rows and columns, according to the designer of the shelf.

-Use of a single material.

Design 3:

Name: DIY Student Furniture

Designer/Brand: Ollé Gellért

Material/Fabrication process: Plastic, 3D print

Price: 21.28$

Description: This design is used to assemble shelves as we can see in photography. With this design we can make furniture of different forms and complexities. It consists of a piece that would make a union between the planks that make up the piece of furniture.


Image 3: Design 3 - State of art

Possible improvements:

-Biodegradable material. A possible improvement in the face of a sustainable and environmentally-friendly product would be to be able to make this product with a plastic, or other material, that is degraded with ease by ending its useful life, whenever possible to continue fulfilling its function and maintaining its necessary properties to do this.

-Have more variety of sizes to make use of sheets of different sizes.

-Use of a single material.

Design 4:

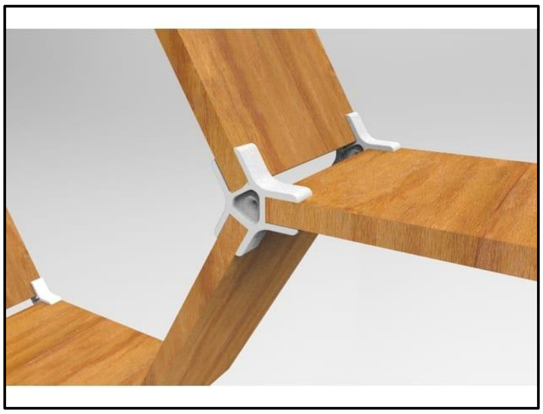
Name: DIY Furniture Joints

Designer/Brand: Desconegut

Material/Fabrication process: Plastic, 3D print

Price: Unknown

Description: This design is very similar to the one explained above, but it is much simpler. You can not make furniture as complex as the previous one.



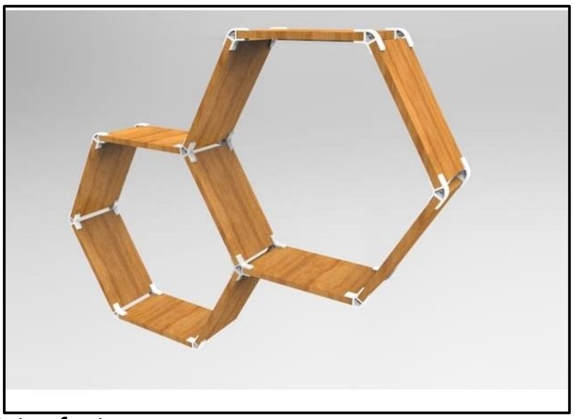


Image 4: Design 4 - State of art

Possible improvements:

-Offer more diversity of ways to assemble furniture from different geometries, that the angles of opening of the pieces are not the same angle.

-To be more creative, when it comes to mounting shelves, or other furniture, add more "entries" of planks, that is, not only can they fit two or three planks per piece but also offer them with 4 board entrances to be able to make the shelf large, gaining rows and columns, according to the designer of the shelf.

-Have more variety of sizes to make use of sheets of different sizes.

Design 5:

Name: Planklip

Designer/Brand: Kickstarter project

Material/Fabrication process: Steel, curving process

Price: Unknown

Descripció: This design is made of metal. It should be noted in this section since it is very versatile and not very

visible. It is easy to use since it is like a clip but larger to assemble the pieces of furniture that you want to build.

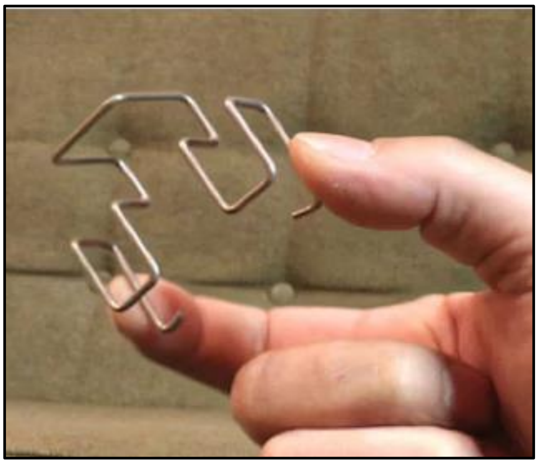


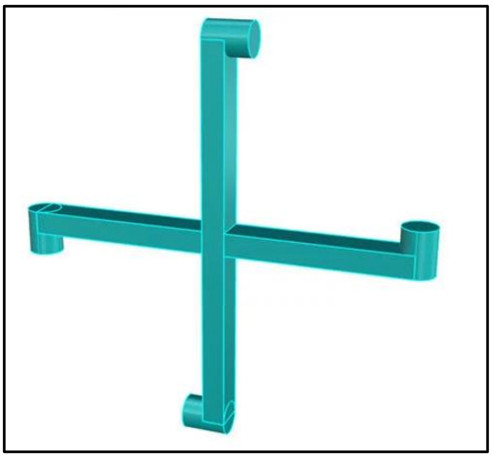
Image 5: Design 5 - State of art

Possible improvements:

-Biodegradable material. A possible improvement in the face of a sustainable and environmentally-friendly product would be to be able to make this product with a plastic, or other material, that is degraded with ease by ending its useful life, whenever possible to continue fulfilling its function and maintaining its necessary properties to do this.

-Have more variety of sizes to make use of sheets of different sizes.

-Use of a single material



Design 6:

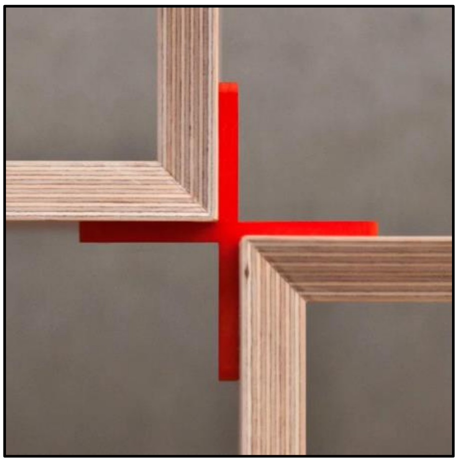
Name: +Shelf

Designer/Brand: Unknown

Material/Fabrication process: Plastic, injection

Price: Unknown

Description: This prototype consists of an X with "teeth" to look at the surface. The design wants to achieve different sets of planks to obtain a piece of furniture.



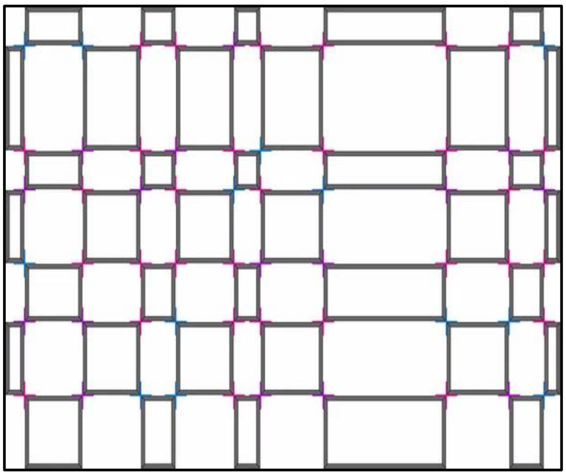


Image 6: Design 6 - State of art

Possible improvements:

-Offer more diversity of ways to assemble furniture from different geometries, that the angles of opening of the pieces are not the same angle.

-Biodegradable material. A possible improvement in the face of a sustainable and environmentally-friendly product would be to be able to make this product with a plastic, or other material, that is degraded with ease by ending its useful life, whenever possible to continue fulfilling its function and maintaining its necessary properties to do this.

-Change the manufacturing process of the piece. This connector is manufactured by injection, a very high price process, a change to make in this product would be to look for a process with which the same properties are obtained but that it is of lower price.

Design 7:

Name: Jonction P

Designer/Brand: Zotrax

Material/Fabrication process: Plastic, injection

Price: Unknown

Description: Jonction P te com a objectiu ajuntar les barres per després poder posar-hi un tauló a sobre per poder fer de taula. És un disseny molt senzill però molt visible.

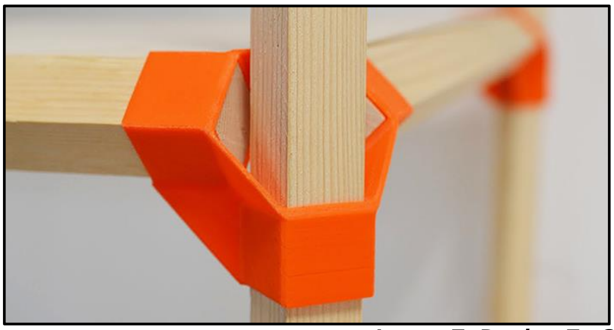
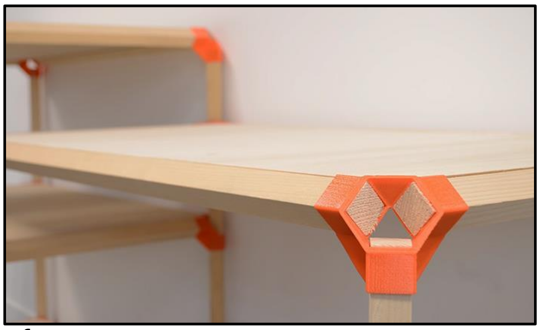



Image 7: Design 7 - State of art

Possible improvements:

-To be more creative, when it comes to mounting shelves, or other furniture, add more "entries" of planks, that is, not only can they fit two or three planks per piece but also offer them with 4 board entrances to be able to make the shelf large, gaining rows and columns, according to the designer of the shelf.

-Biodegradable material. A possible improvement in the face of a sustainable and environmentally-friendly product would be to be able to make this product with a plastic, or other material, that is degraded with ease by ending its useful life, whenever possible to continue fulfilling its function and maintaining its necessary properties to do this.

-Have more variety of sizes to make use of sheets of different sizes.

-Change the manufacturing process of the piece. This connector is manufactured by injection, a very high price process, a change to make in this product would be to look for a process with which the same properties are obtained but that it is of lower price.

4.2 Final election

In this section, mention is made of the references which can help with the final design decision. Although the designs seen in the state of art are very far away from the proposal of this project, there are certain elements that will be taken into account in the design of this project. The points analyzed are those that are detailed below:

Manufacturing process: it is considered if the manufacturing process of the piece is appropriate for manufacturing in series.

Sustainability: it is evaluated if the product can be made with a material that is less harmful to the environment, which both in its manufacture and disposal at the end of its useful life it pollutes less.

Costs: If you can make the product with a material with lower price or with a cheaper manufacturing process.

Geometry: as seen in the possible modifications of each reference, it is considered if it allows building the piece of furniture with different angles or you can only attach boards / profiles to 90 degrees.

Profiles size: it is considered if it allows to assemble different planks / profiles of different thicknesses

Design: It is considered if it allows you to join planks / profiles in the three directions of the space; vertical, horizontal, forward / backward.

Assembly: facility of assembly, if the use of Allen keys or screws is necessary.

Extensibility: possibility of modifying some part of the geometry of the product, how could it be to extend a part of it.

4.3 User analysis

This section pretends to study in depth the users and their needs.

1. Users

- Editor: responsible for using the object in question to built a piece of furniture.
- Owner of furniture: to be able to design a piece of furniture (in the case of our project a Bookshelf) with the features that are wanted.

- Shop: in charge of selling the product to the end user. It should be taken into account that in selling online there would be a shop owner/seller.
- Engineer and Designer: responsible for the realization of the project, must give their approval with regard to the design of the product and its features.
- Manufacturer: responsible for the manufacture of the product, from the procurement of raw materials to the final product finished and conformation. As this project is more of a assembly of different pieces and joint ventures, the origin of manufacture of these can be diverse.
- Competition: companies that want to have the best products.
- Recycling Staff: responsible, once finished the life of the object or during their manufacture,to well recycle or the trash generated.

2. Types of users and needs:

- Aesthetics
- Durability
- Cost
- Easy assembly
- Recyclability
- Easy manufacture

USERS	**NEEDS**	**DEMAND**
User	• Easy building	
Owner	• Cost • Resistance • Aesthetics • Durability	• Easy to built • Low cost • Good looking • Secure

	• Quality	• Resistant materials
Shopkeeper	• Cost • Exclusivity • Simplicity of assemblies	• Good looking • Low cost
Manufacturer	• Energy and economic cost • Easy manufacture	• Easy material to obtain in the market • Simple manufacturing • Easy recycling
Competence	• Low cost • Better products	
Recycling staff	• Reduce, recycle and reuse 3R • Durability	• Reduce waste

Table 1: Comparative user analysis

4.4 Functional analysis

By means of the functional analysis it is necessary to complete the description of the problem and the characteristics that the new design wishes to fulfill.

Based on the needs of the users, criteria and values that define the characteristics of the project are decided.

The table is composed of the needs found and the importance of the proposed functions. Below the table, a short explanation on the criteria on some of the needs.

The value of the importance will be marked when designing the product to what needs will be given priority. The level of priority is imposed based on the objectives of the project, because if one of them, it will be given greater importance.

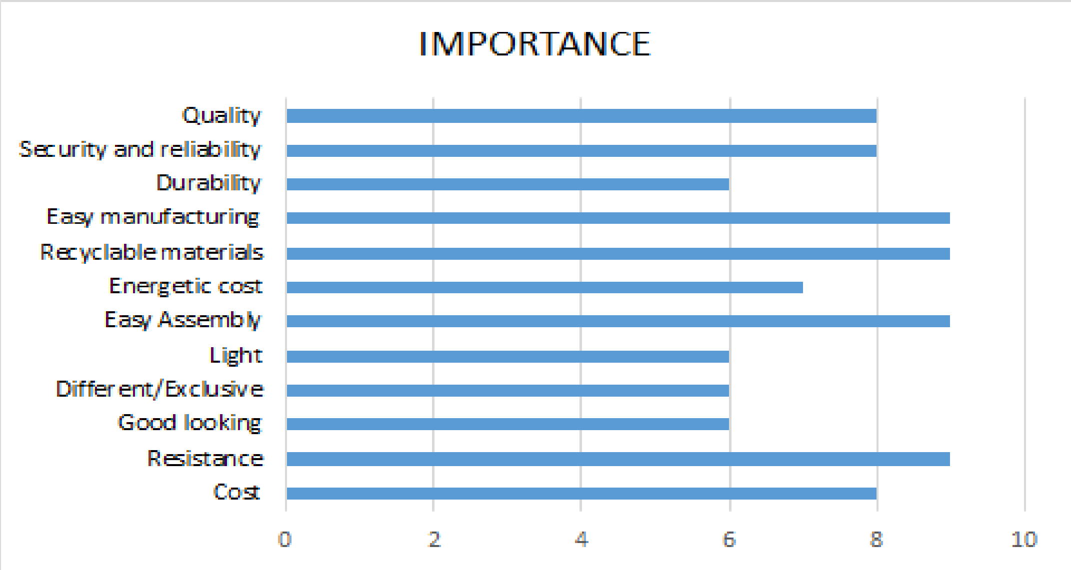


Table 2: Functions importance

For some elements, a criteria has been defined. The following are: Cost is measured in €, the resistance is measured with the weight that can be held in Kg (or N), the energy cost in kW, the manufacturing process with the number of processes, and the durability with the years of useful life.

5. Product design

5.1 Conceptual design of the module

In the market study (state of the art) that has been done in point 4.1, we have seen several applications similar to those that this project wants to bring. Obviously, there are some who are too far away from the project, but there are some that contain some elements or ideas that can be used as inspiration for the design of the modules in this project. Below is a list of a series of properties that will be taken into account in order to design of the modules:

- Diversity of shapes: In design 2 a union can be seen in a very unusual way but, nevertheless, it serves as the support of a table.

- Resistance: Design 5, made of metal, guarantees this property.
- Lightness: Any of the designs complies with this property.
- Simplicity: Design 7 is simple, but very visible.
- Color and personalization of the product: Designs 1, 7 and 6 are very bright colors. On the one hand it could be an advantage, but on the other it deprives the module / union to remain hidden.
- Being 'hidden': There is no design that meets this property. This is something that will be taken into account when making module designs.

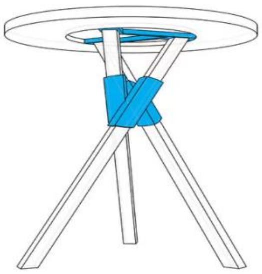
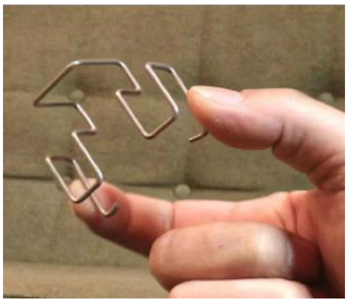
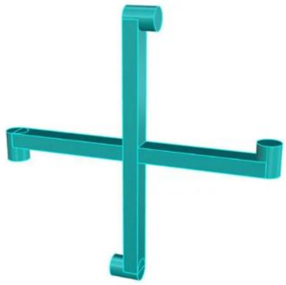
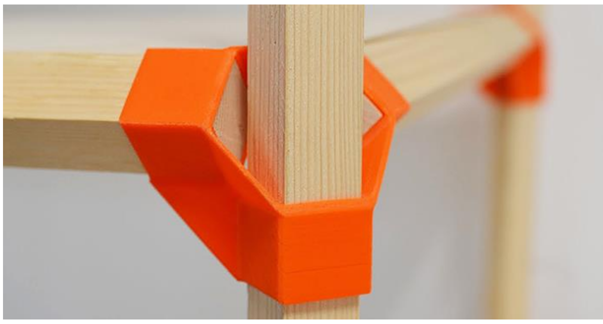
 DESIGN 1	 DESIGN 2	 DESIGN 3
 DESIGN 4	 DESIGN 5	 DESIGN 6
 DESIGN 7		

Table 3: The different designs of the State of art

As we have just seen, there are a number of properties, seen in the study of the state of the art, which are indispensable for the design of the modules. Others, such as the color / personalization of the product, or the diversity of forms, are not so much.

This project is intended for the design of the modules that will unite the wood to assemble the furniture and not the woodwork, so it is desired that the design does not excessively complicate the machining of wood.

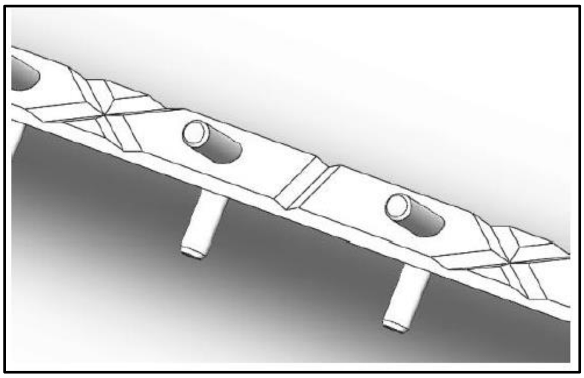
So far, we have looked at how to design the modules by looking at the characteristics of the references with which you want to compete or copy parts of them in order to create a better product. Apart from this, it should be considered that the design of the module, the geometry, does not complicate the machining of the woods where it will be mounted, because it has been seen that it can be a problem.

Looking at the furniture of the market, the easiest thing is to copy the system, through holes, which can be done with a drill, where parts of the module are located to fix the furniture. Therefore, the design must have some 'little blocks' that play the role of the screws.

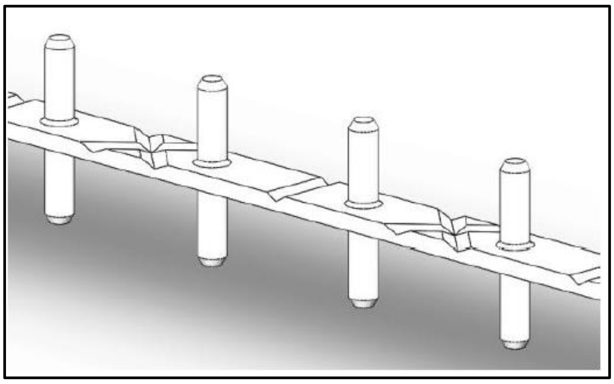
With this, the following point presents the three already known proposals and the final election for this project is explained in detail.

5.1.1 Introduce old designs

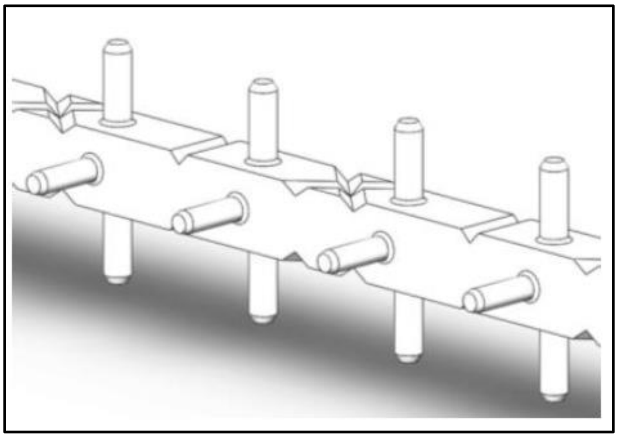
Below are 3 images that correspond to designs already studied in the project that proceeds this one. Reference of this previous project can be found here: *Novell/Fernandez 2018* http://hdl.handle.net/2117/118318



V design



I Design



T design

Image 8: Different modules of blocks

These elements have the blocks to be able to be fitted to the wood and straight and "X" slots to facilitate cutting them. The idea of this is to cut the modules by adapting it to the needs of the furniture that you want to assemble. In this way, if you want to unite two pieces of wood but it is thought that they do not need so much weight, they can be put less, as long as the structure holds out and therefore does not fail.

Straight slots allow cutting the element to get ends with straight angles. On the other hand, the X slots are made to allow an end to be finished with an angle of 45º.

One thing common to the 3 types of modules is the distance between blocks. The fact of having a standardized distance for all 3 facilitates the assembly of the furniture.

The big difference between them is that each one allows different unions between wood planks; the module in T allows to unite 3 planks, the module in V allows to unite two planks that make corner and finish with an angle of 45º and linear to join the planks in parallel.

A slot in the base of all the blocks was also designed in the previous project (see image below) in order to facilitate the cutting of these if necessary. The subsequent study (simulation of the structure) was made and it was seen that it did not support the efforts well, since great tensions were concentrated in that area.

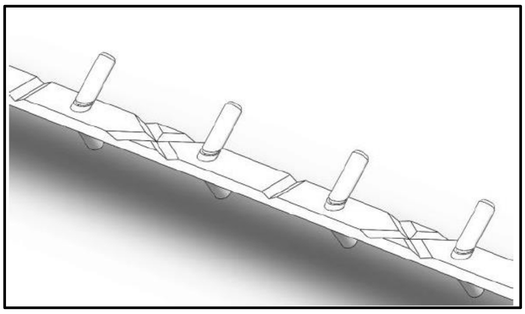
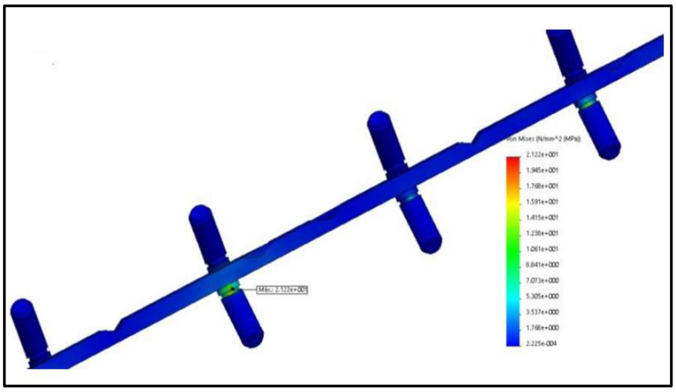
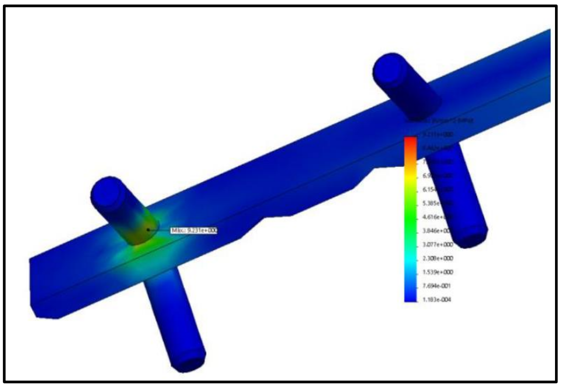


Image 9: Module in V with slot in the base of the blocks





In the previous images you can see two identical simulations in everything except for having/not having a slot in the base of the blocks. In the previous project it was already shown that with slot the tensions were concentrated there, exceeding the elastic limit of the material. On the contrary, without a slot, these were kept below it. This has been taken into account in the design and study of the unions in this project.

5.1.2 Selection of the model to be used: module in I

After having analysed the state of art and having studied in detail the 3 designs that are shown in 5.1.1, a single module was chosen that could be used to assemble a whole piece of furniture. That is, with a single module, all the unions of a shelf can be solved.

The chosen module is that of design in I.

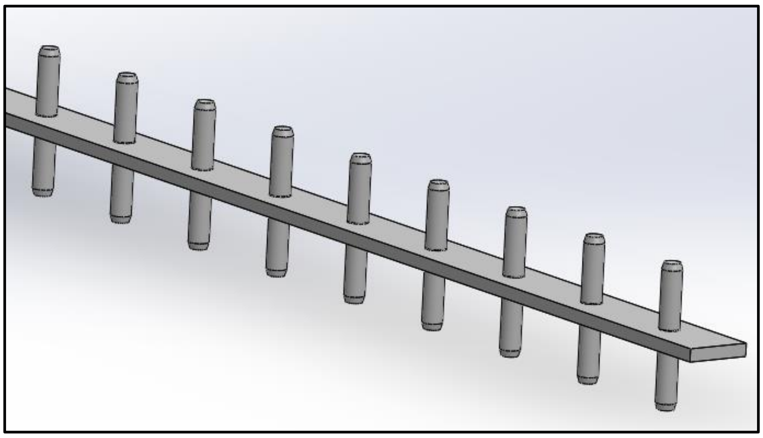


Image 10: Final design of module in I

Although not an easy choice, a reference shelf was taken and we saw if it would be feasible to solve all the unions with the module in I.

Below is the shelf that was chosen, extracted from the IKEA catalog. Although there are some elements that we will dispense with, as a general idea it already served. All the joints between wooden planks of the furniture can be solved with the module in I.

Image 11: Shelf of reference of the IKEA catalog

Having said that, it was thought that this union deserved an in-depth study. Basically find an optimum number of pins (frequency of thighs and thickness of these) which allowed assembling the piece of furniture without failing anywhere.

The study is detailed in point 5.3.

5.2 Choosing the furniture of study: bookshelf

In this project you want to get the user to take advantage of this design to easily assemble a piece of furniture. In this section, a market study has been done to see which furniture is most used and one that is adapted to the needs of this project.

At first it was thought that this furniture could be a shelf for wines, but in the end it was decided that the furniture would be a shelf, more like a wardrobe, of larger dimensions than the ones of the winery.

Below are the different shelf designs with their specifications and what is the final decision.

1) Bookshelf with accessories KALLAX - IKEA

Assembled size	
Base	147 cm
Depth	39 cm
Height	147 cm
Max weight	13 kg

Image 12: Example of furniture

2) Shelf YPPERLIG - IKEA

Assembled size	
Base	90 cm
Depth	35 cm
Height	166 cm

Image 13: Example of furniture

3) Shelf KALLAX - IKEA

Assembled size	
Base	42 cm
Depth	39 cm
Height	112 cm

Image 14: Example of furniture

4) Shelf EKET -IKEA

Assembled size	
Base	35 cm
Depth	35 cm
Height	35 cm

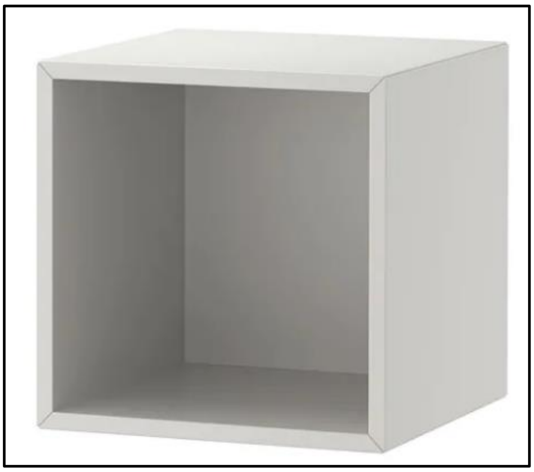


Image 15: Example of furniture

5) Shelf ELVARLI - IKEA

Assembled size	
Base	165 cm
Depth	55 cm
Height	216 cm

Image 16: Example of furniture

Once a few shelf designs have been seen, the final decision is as follows: The furniture has 3 identical shelves on the left side, in the lower right corner a small one, and at the top right a larger area. There are, as will be explained in the point 5.3.5, some additional elements that may be added.

Assembled size	
Base	150 cm
Depth	60 cm
Height	190 cm

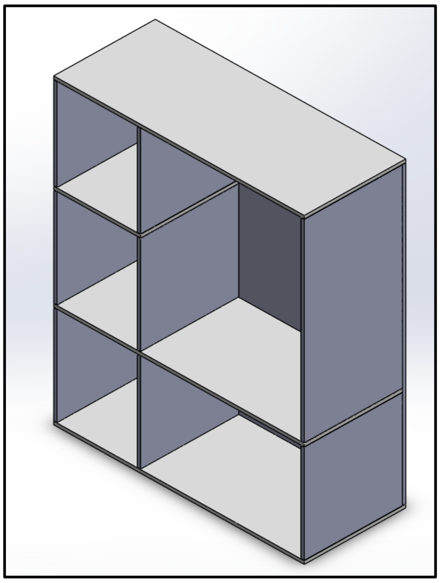


Image 17: Final furniture

This design has been chosen because it is believed to be the most optimal in terms of utility and relatively easy to build, it can be made of wood and the measures are ideal to store any object (shirts, shirts, shoes, boxes ...). This design is very similar to ELVARI - IKEA, but with a little modification so that it can be more useful and to introduce all the accessories that also want to be implemented.

Here are all the specifications of each of the pieces that make up the furniture (the unions are not included) and a image with the exact position of the pieces.

1.Drawer:

This wood will be the one that will be supported by the upper left drawer.

The holes are on both sides as we can see in the image at a distance of 10mm from the corners.

Measures: 600x530x20mm

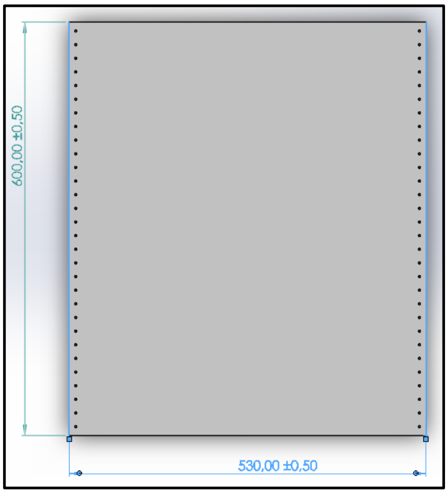


Image 18: Part of the final furniture

2.Large drawer:

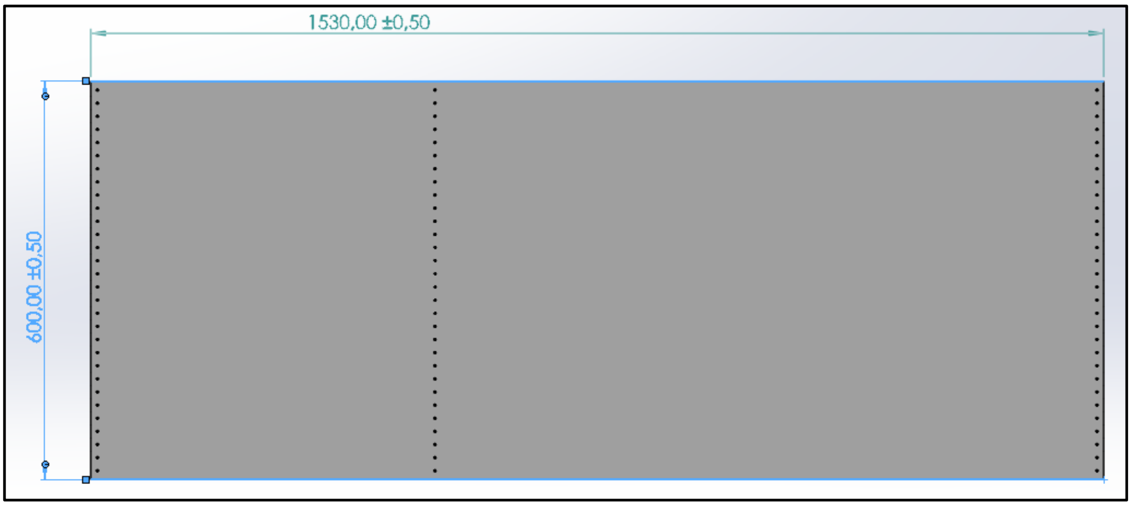


Image 19: Part of the furniture

This will be the piece where later the sliding will install and also it conforms the second drawer of the piece of furniture.

The holes can be seen in the image and are on both sides and have another in the center.

Measures: 600x1530x20mm

3. Side1:

This piece has just shaped the upper left drawer of the piece of furniture.

It will be drilled vertically both up and down and will also have the bar holes on one side.

Measures: 580x600x20mm

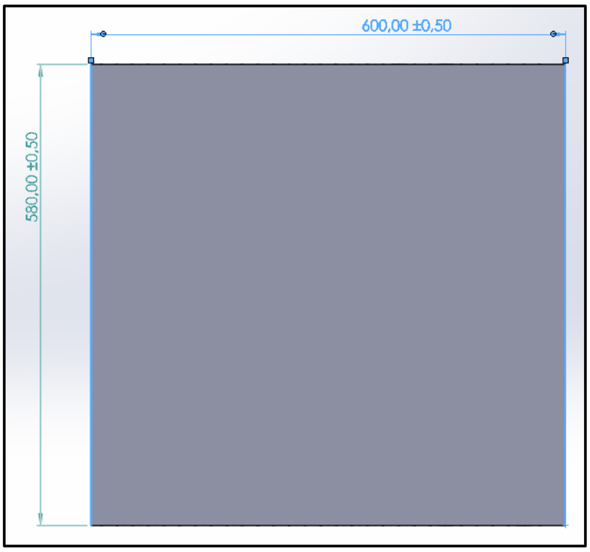


Image 20: Part of the final furniture

4.Side2:

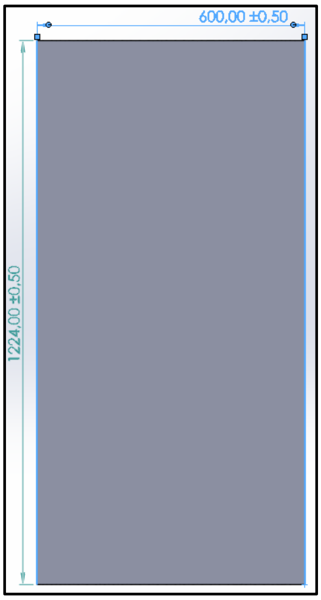


Image 21: Part of the furniture

This piece is the union between the sliding and the ceiling. It is identical to Side1 and Side6 with the difference in the height level.

Holes are both up and down vertical.

Measures: 1224x600x20mm

5.Side6:

This piece conforms most of the furniture as it is found in many parts of the furniture. It serves to attach the two drawers, the drawer on the bottom with the floor and the sliding floor. It is similar to Side1 with the difference in the height level.

Holes are both up and down vertical.

Measures: 620x600x20mm

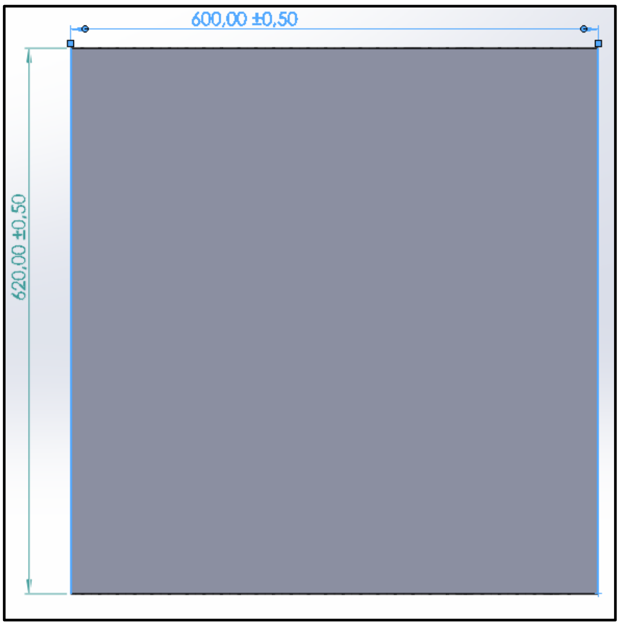


Image 22: Part of the furniture

6. **Floor and ceiling:**

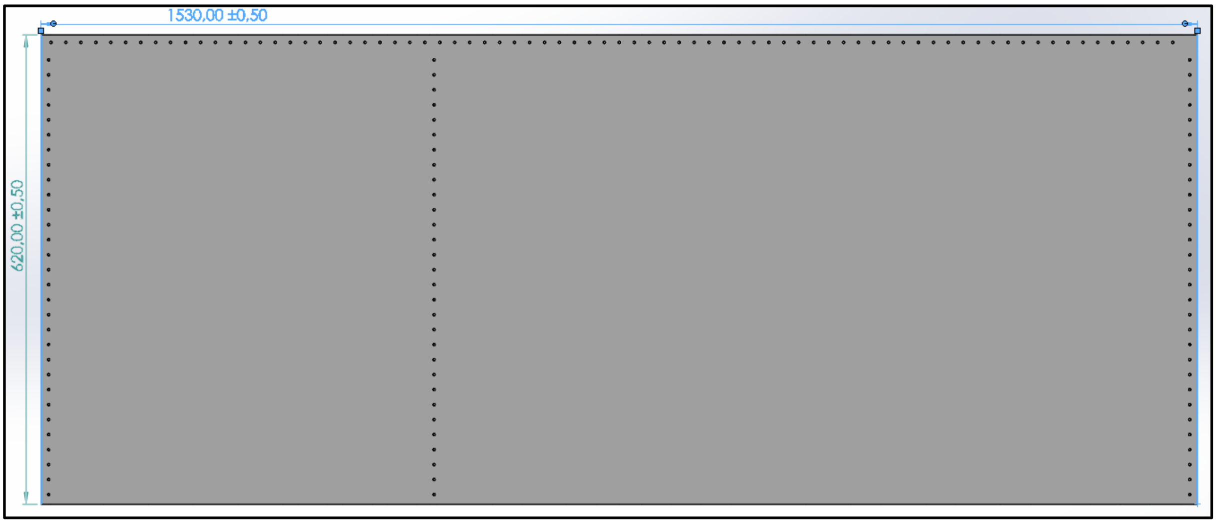


Image 23: Part of the furniture

Both the ground and the ceiling go together in this point since they are completely equal with the difference that the center holes are anti symmetrical.

As you can see in the image, the holes are located along the sides of the pieces and others through the center.

Measures: 620x1530x20mm

7. **Cover:**

This piece will cover the furniture and will make contact with the wall.

Holes are both up and down vertical.

Measures: 1868x1530x20mm

Image 24: Part of the furniture

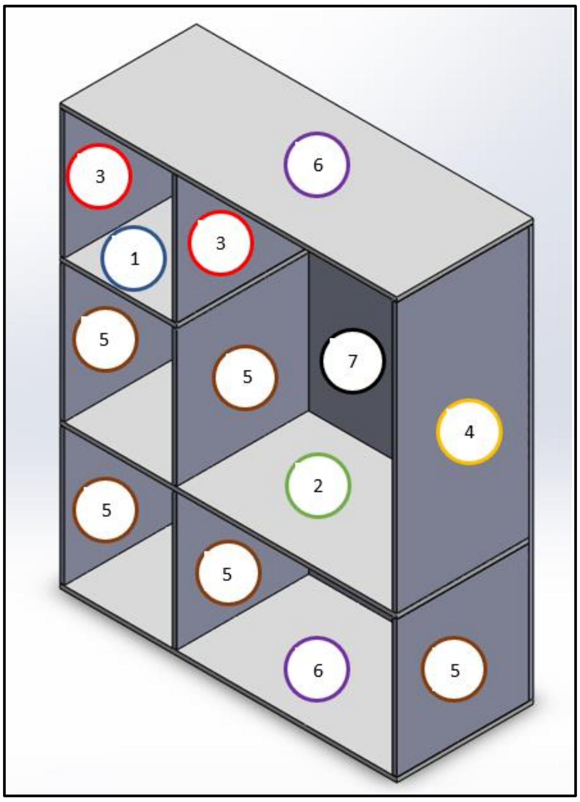


Image 25: Image with indications about which part of the furniture is

5.3 Validation of the design

The simulations are done to see the tensions that the design element of this project can sustain.

For this reason, the equivalent tensions are located and compared to the elastic limit to analyze if it is sufficiently resistant.

To study the behavior of the element, different cases are studied in which it can be found in its useful life.

It is easier to do the simulations with the modules built inside a piece of furniture where you know the strength that must be supported other than having to calculate the force that must be supported by the modules once assembled, which is why simulations are done with furniture, as they will be used if the results that are obtained are valid.

The different situations in which we put in the study item are to see if this once mounted in a piece of furniture will be able to support the weight that would support a piece of furniture built with a traditional system. The item is placed under different conditions applying forces of up to 300 N.

5.3.1 SolidWorks Simulator

The software used to perform simulations is Solidworks Simulation, a component of Solidworks, a program with which the designs have been made. This is a design software focused on engineering.

SolidWorks Simulation contains a relatively easy-to-use structural analysis tools package that uses the finite element analysis method (FEA) to predict the actual physical behavior of a product through virtual CAD models. The program provides static and dynamic analysis capabilities, but only static-type simulations will be made in this project.

The different simulations are executed under the same program conditions. Applying contact between assembly components, these contacts are global for all of them. The applied restriction is of non-penetration, that is, that the pieces can be touched and separated but never superimposed on each other.

5.3.2 Conditions

The following are the conditions that the model must meet in order to give it as valid. In the same way the properties of the materials introduced in the program and finally the conditions of the user will be shown.

5.3.2.1 Mechanical conditions

CONDITION 1	The maximum stress is lower that the elastic limit of the material
CONDITION 2	The displacements in the X, Y and Z directions are less than or equal to 2 mm in the module.
CONDITION 3	The displacements in the X, Y and Z directions are less than or equal to 5 mm in global, including the ones in the wooden planks and in the modules.

As for the stress it is mostly checked in the modules, because they are the object of study of this project, the one of the wood is commented only in the case that is very high. The third condition, displacement in global, it's checked but it is not the most important condition, because if these values are different from those of condition 2 it implies that they are displacements to the wooden planks and these depend on the mechanical properties of the wood. For that reason simulations with two different woods are made, to see how the type of wood affects the results. Being the most important that the conditions of the module are not significantly affected by the type of wood.

The maximum displacement value, both in condition 2 and condition 3, can be both positive and negative, you look at the absolute value which is the highest you get.

In all simulations, the same boundary conditions are applied, the base of the vertical planks is fixed and different forces are applied to the planks.

Regarding the properties of the materials introduced in the program, they are the ones that are shown below.

	ABS	BEAM WOOD	WOOD 1
Young Module	1400 N/mm^2	639.6 N/mm^2	3000 N/mm^2
Poisson's ratio	0,33	0,41	0,29
Density	1020 Kg/mm^3	340 Kg/mm^3	160 Kg/mm^3

Elastic limit	20 N/mm^2	50 N/mm^2	20 /mm^2

Table 4: Specifications of the materials of the simulations

5.3.2.2 User conditions

This section presents the user conditions. These will be taken into account, together with the mechanical conditions, in the design of the union modules.

CONDITION 1	Reduce the number of blocks per module to the minimum, in order to make the assembly for the user more convenient and easy, as well as to reduce the use of material.
CONDITION 2	Customizable furniture so that the user can adapt it to his needs.
CONDITION 3	We want the materials to be used as resistant as possible, but also have an economic price.

5.3.3 Meshing

A mesh based on curvature that is best suited to the problem has been applied, this mesh uses triangular elements.

Before starting with the simulations, the module meshing is done to see if it is done correctly.

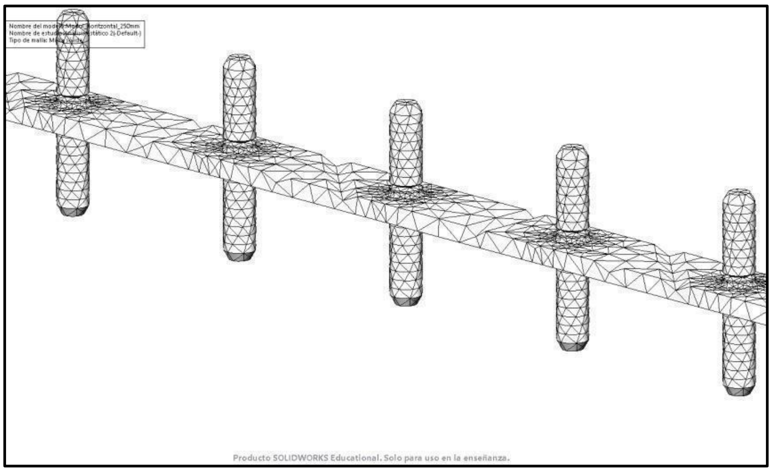


Image 26: Module in I with slot on its base

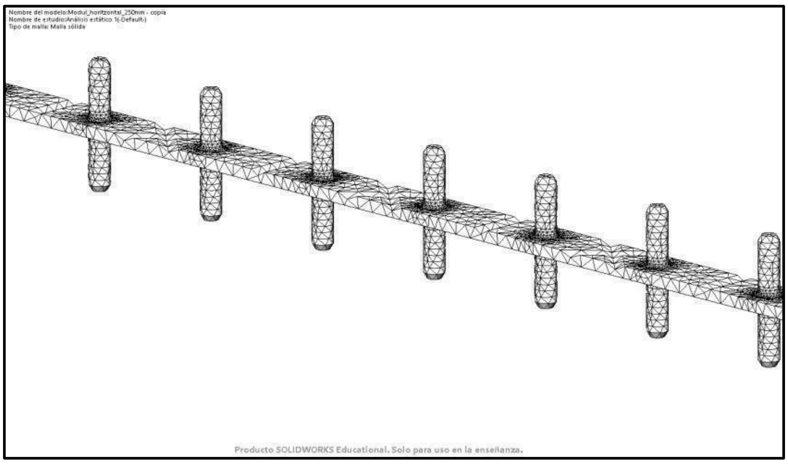


Image 27: Module in I without slot on its base

To make this mesh, a mesh control has been applied with the following properties:

- Fine density of mesh
- Size of the elements: 2mm
- Ratio a / b 1.5mm

As per the mesh of the planks, we have made it more thick because it is not so relevant in the study. However, simulations have also been performed with a finer mesh as it would be more accurate.

It has also been seen that in the modules, at least there must be 2 elements per thickness. The result is shown below:

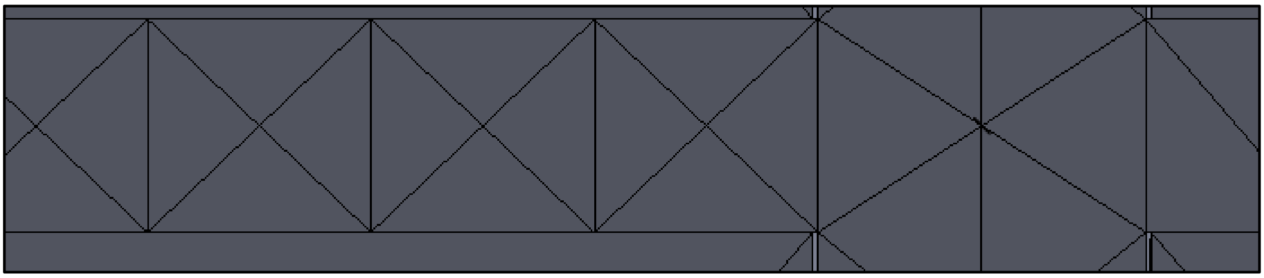


Image 28: Description of the mesh

5.3.4 Optimization of the module in I

One of the objectives of this project is to be able to find the optimal frequency of the joining elements, as well as the optimum thickness of these. With regard to both conditions, a series of simulations will be made that are shown in 5.3.4.2 which make it easier to find this optimum.

Regarding the optimal frequency of the blocks, we want to find a distance between them that allows to support all the efforts of the shelf. The ideal would be a low frequency (in order to save material in 3D printing) but without altering the stability of the furniture.

Regarding the thickness of the blocks, it will be studied to see how this factor affects the stability of furniture and stress (Von Mises) of the blocks. At the time of deciding the thicknesses of the blocks we will take into account the types of drill that are in the market, so that our model is adapted to the maximum to the reality, and the user does not have any trouble when building the piece of furniture.

5.3.4.1 General simulation (all the furniture with all loads)

At the beginning of the simulations, we thought about the idea of simulating all the furniture, with all the unions and all the applied forces. Immediately it was seen that it was impossible to perform a global simulation of the entire shelf. This is one, as specified in section 3.3, of the project limitations. The number of degrees of freedom was way to too large and therefore it would have been impossible to complete the simulations. The only more or less viable way would have been to do a thicker mesh everywhere. Anyway, as it was important to see the tensions in the unions in I and these are of small dimensions, the option was discarded.

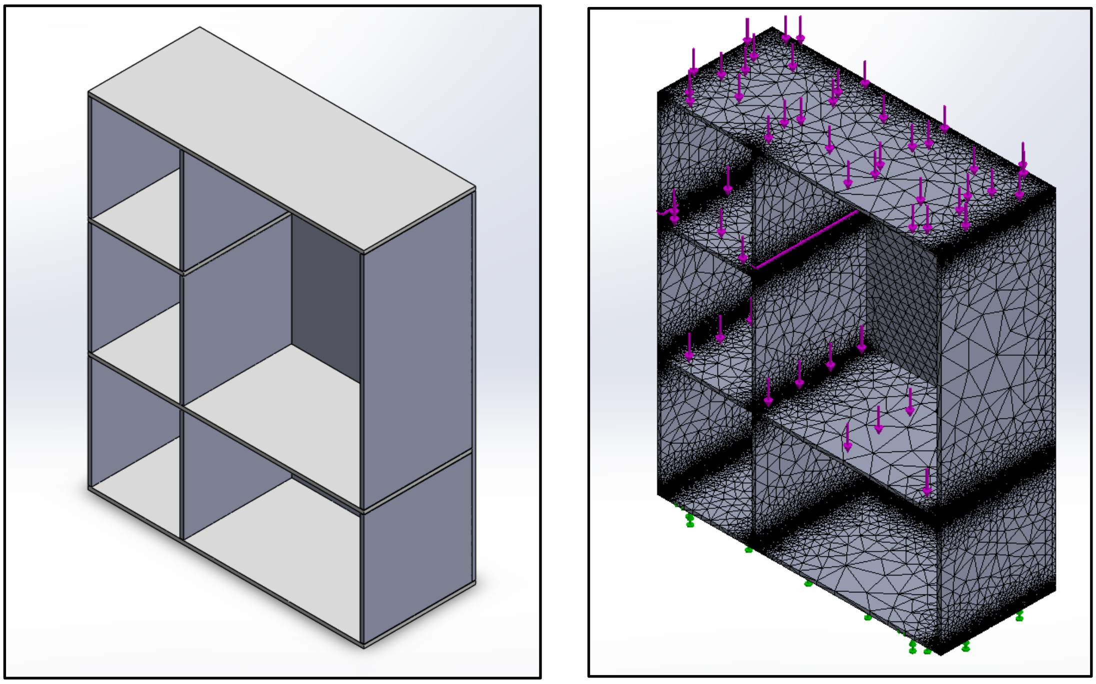


Image 29: Furniture with and without meshing

Due to the difficulty of the calculations of stress and displacements that was to make the simulations with a whole piece of furniture, it was decided to study a local area of the furniture.

The various areas that could suffer more effort during the useful life of the furniture were analyzed and the conclusion was that the upper lid of the lower right part of the furniture. For simulations, a **vertical force between 200 and 300 N** will be assumed.

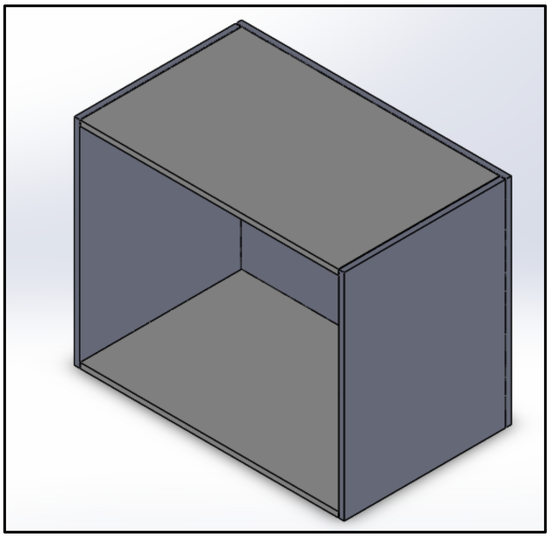
This simplification greatly reduces the number of degrees of freedom of the study, and therefore the simulation time as well.

It is believed that this model will be valid since the subjections of this piece will be equal, or proportional, to the rest of the furniture.

5.3.4.2 Local simulation: Optimization of the blocks

- **First simulation: first design**

In this first simulation a horizontal I union was used, as shown in the photo.



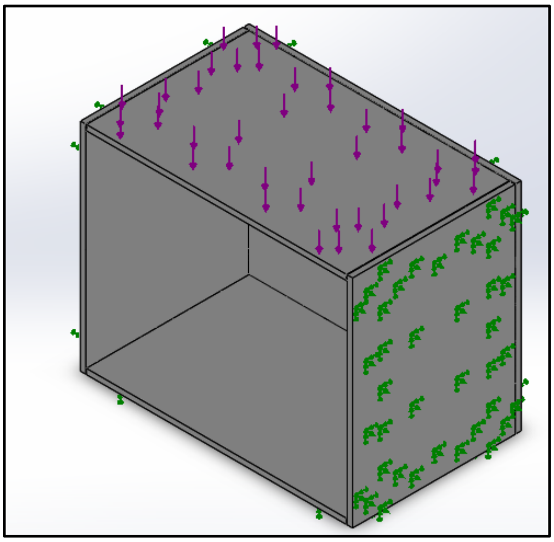


Image 30: Model to simulate

This configuration is composed of the following elements:

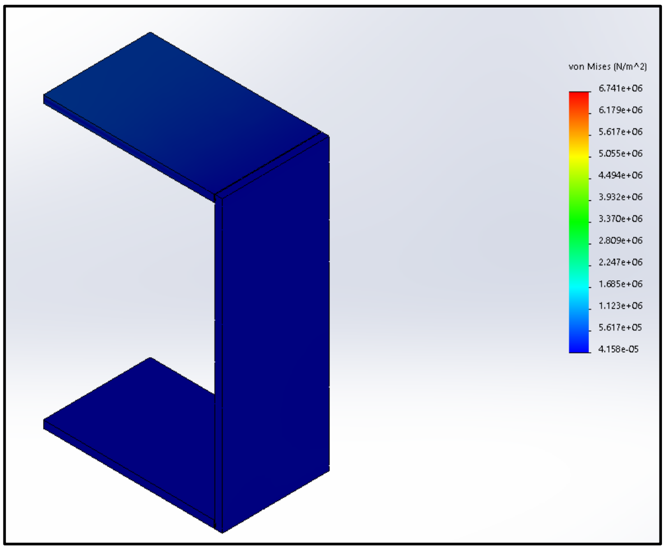
- 2 wood planks of 960x600x20mm
- 2 wood planks of 600x800x20mm
- 1 wood plank of 800x1004x20mm

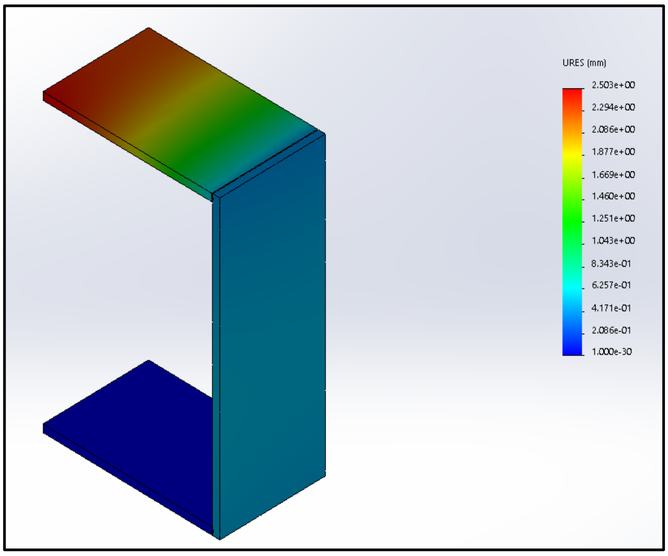
- Module of 30 blocks

The wood used was **BEAM WOOD**.

After applying the study conditions explained, it was simulated and then the results are shown.

The results that are shown after each simulation are the following: First, the Von Mises stress diagram of the whole simulated structure. If needed, a complementary image of a detailed area is shown. Second, a displacement diagram (URES). The module displacement is checked but if it is low, no image or comment is included. Third, the unitary stress diagram is included (ESTRN).





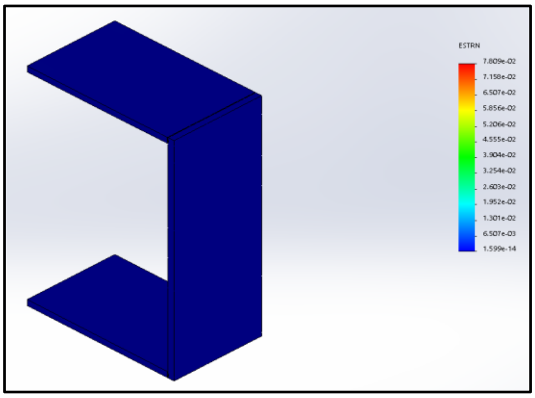


Image 31: 1st Simulation results

As for the tension of Von Mises, the modules have a maximum tension of 6.741 MPa. Therefore Condition 1 is met because this value is lower than the elastic limit of the material.

Regarding the displacement, they are of the order of 2.503 mm, but being a horizontal junction, the sideboard is also deforms (0.8 mm) which is not convenient.

This fact shows that in reality with this configuration the furniture can hold but can cause problems if it is extrapolated to all the furniture, for this reason, it was decided to solve the union (and all the others on the furniture) with the union in I in Vertical.

- **Second simulation: new design**

Once redesigned the shelf, with all the unions solved with union in vertical I, proceeded to perform a new simulation of the structure. To do this, unions with 30 blocks were used, which were considered large enough to do a first study.

Below is the assembly detail:

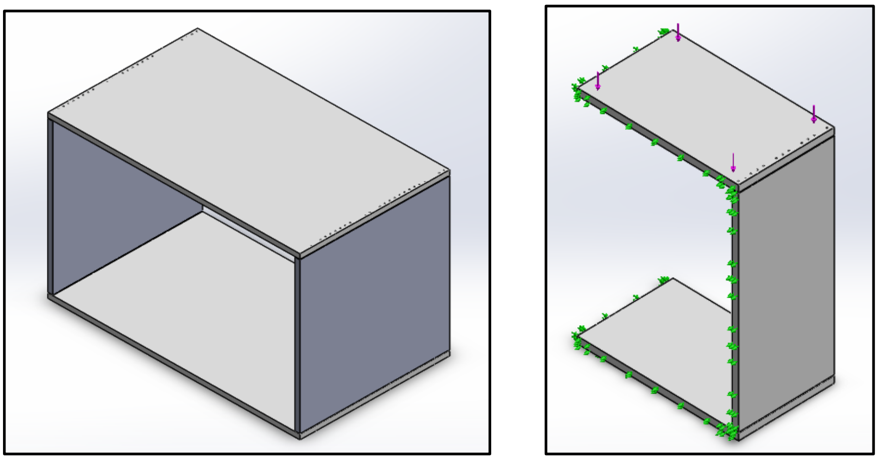


Image 32: 2nd model to simulate

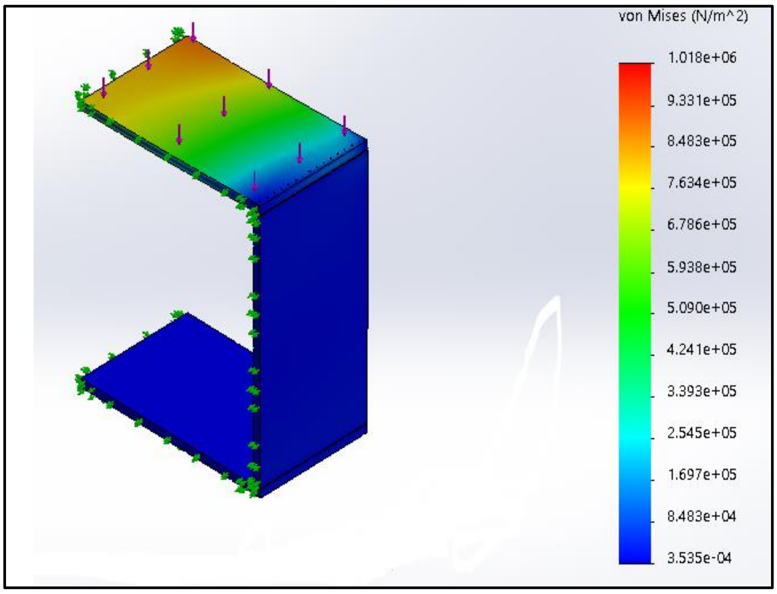
As shown in the previous image, to perform this simulation (and many of those that will come) symmetries were used. Specifically, 2 symmetry plans were used. The fact of working with symmetries greatly simplified the simulations. The number of degrees of freedom went from around one and a half million to about 100 thousand. (although it obviously depends on the accuracy of the mesh). The fact of having much less degrees of freedom reduced the simulation times of 1 hour or so to 20 minutes. Therefore, from now on the results are shown with a quarter of the area of study since it is (in fact, it is) that the results are symmetrical.

This configuration is composed of the following elements:

- 2 wood planks of 620x600x20mm
- 2 wood planks of 600x1010x20mm
- Module of 30 blocks

The wood used was **BEAM WOOD**.

After applying the study conditions explained, it was simulated and then the results are shown:



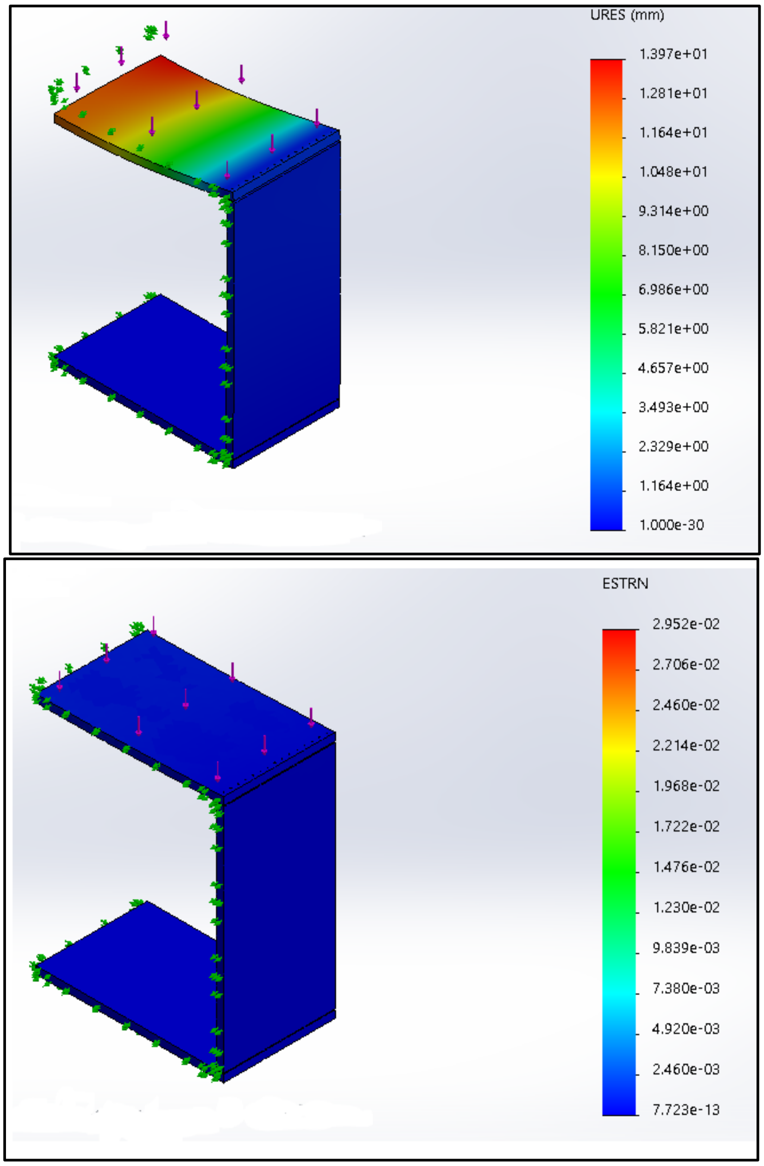


Image 33: 2nd Simulation results

The results that have just been shown of this simulation are much better than the first simulation, made with the union in horizontal.

As far as the displacements are concerned, it is logically maximum at the center of the board. (URES mm graph). The maximum value shown is 13.97 mm. We would be talking about 1.397 cm. Under the conditions of this project, there is a smaller displacement limit and therefore will not comply with this condition. In any case, it is not a value at all big considering that the upper wooden board has a length of 1.01m. In any case, this displacement is considered invalid since it is superior to the conditions specified in section 5.3.2.1.

As for the Von Mises stress, the maximum is 1.018 MPa. This is not in the center of the board, but in the union in I. This could be a problem because the union could fail, but this value is much lower than the elastic limit of the material, in this case the ABS . The detail of the maximum stress point of Von Mises is shown below.

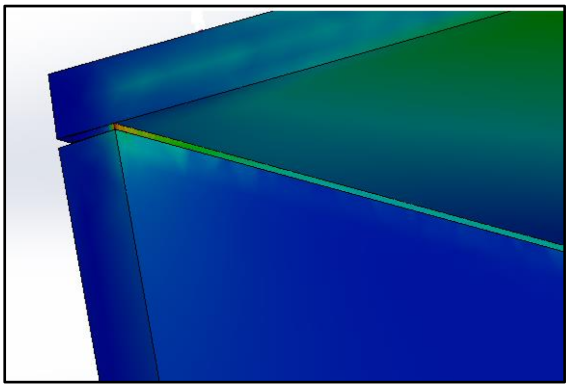


Image 34: Detail of the maximum Von Mises stress

Therefore, in this simulation we have been able to see that the condition of displacements is not fulfilled.

- **Third simulation: new material**

In this simulation the previous procedure was repeated but changing the type of wood. In the 2nd simulation the **BEAM WOOD** was used and did not comply with the mechanical conditions.

This configuration is composed of the following elements:

- 2 wood planks of 620x600x20mm
- 2 wood planks of 600x1010x20mm
- Module of 30 blocks

The wood used was **WOOD 1.**

After applying the study conditions explained, it was simulated and then the results are shown:

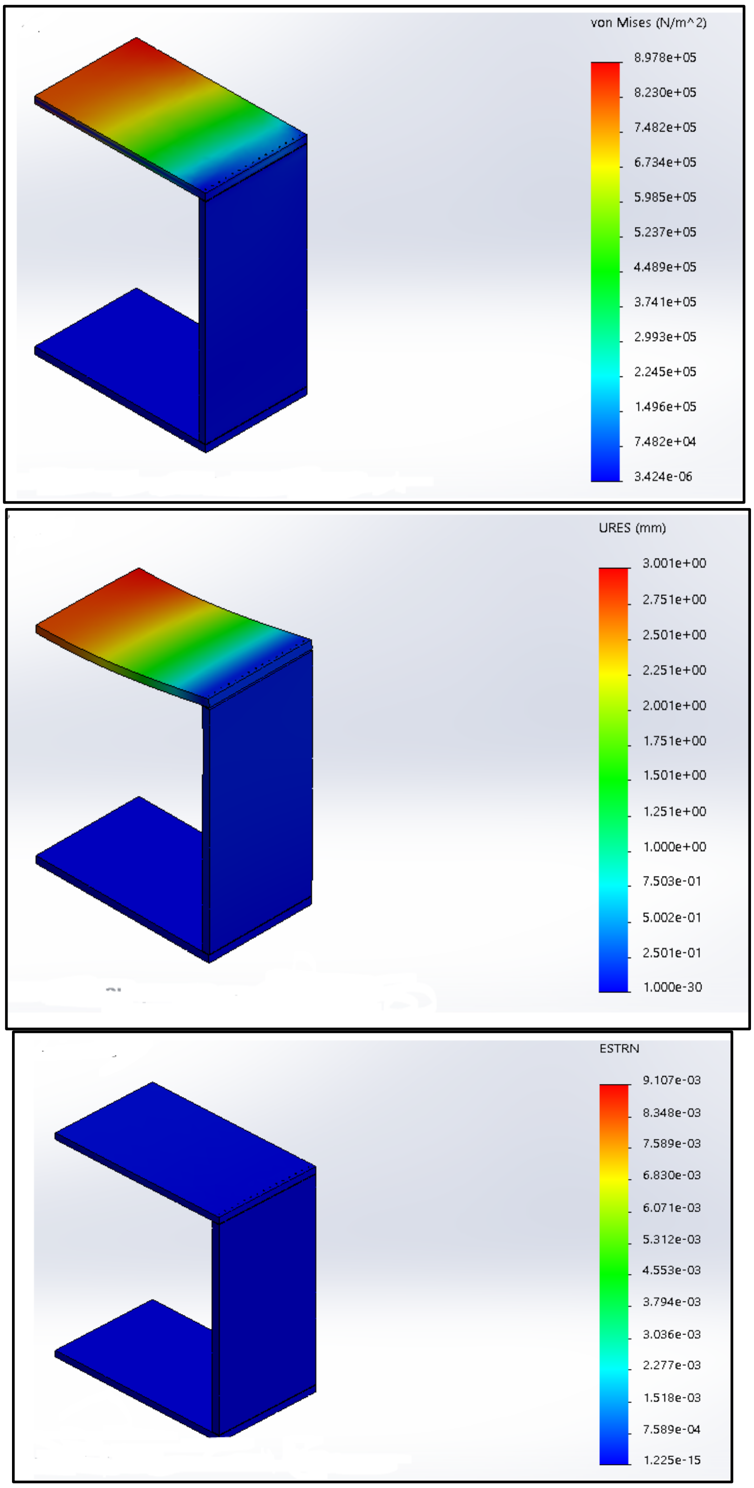


Image 35: 3rd Simulation results

In this case it is seen that the mechanical condition is fulfilled. The maximum value of the displacements, in the center of the upper board, is 3.001 mm.

As for the tension of Von Mises is 0.8978MPa. Much lower than the elastic limit and therefore condition 1 is also fulfilled.

So, from now on, we will work with the **WOOD 1**.

As it is shown in the section of the selection of materials (**point 7**), those chosen for the simulation are not necessarily the same ones that must be used later to assemble the furniture. It is of the choice of the user to use one type of wood or another.

Once we have seen that the results obtained in the previous simulation meet the mechanical conditions that the model must fulfill so that it works correctly, we decide to do another simulation with a finer mesh to obtain more accurate results.

- **Forth simulation: mesh improvement**

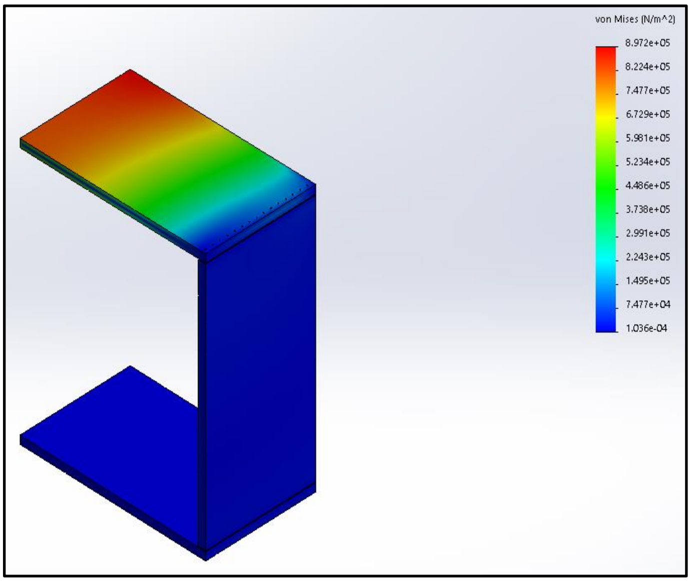
In this simulation, the previous procedure was repeated, but changing the type of mesh to obtain more accurate results.

This configuration is composed of the following elements:

- 2 wood planks of 620x600x20mm
- 2 wood planks of 600x1010x20mm
- Module of 30 blocks

The wood used was **WOOD 1.**

After applying the study conditions explained, it was simulated and then the results are shown:



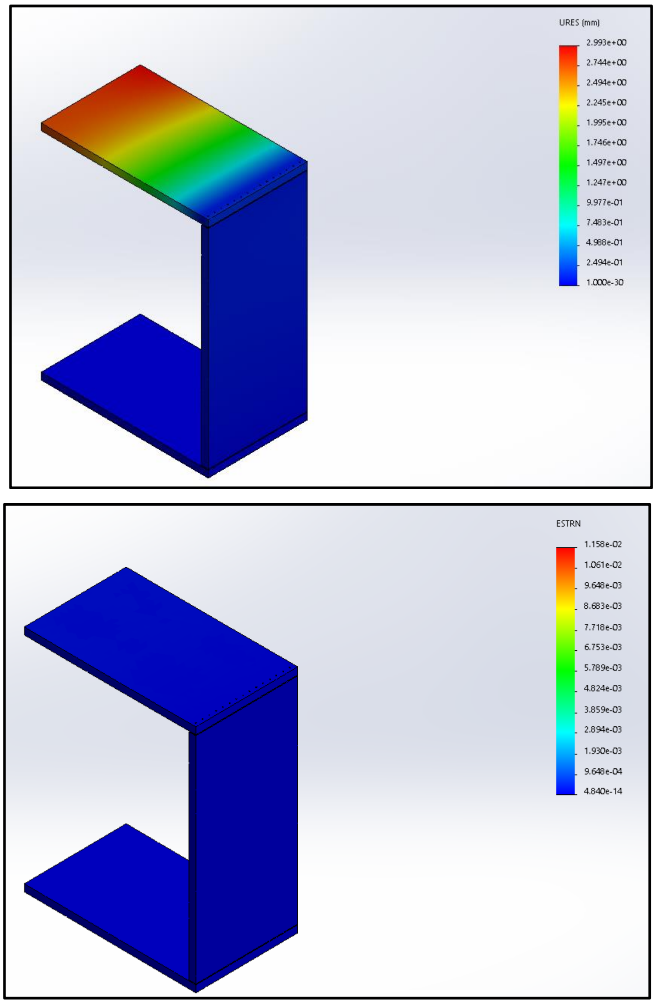


Image 36: 4th Simulation results

In this case it is seen that the condition of displacements is fulfilled. The maximum value, in the center of the upper board, is 2.993 mm.

As for the tension of Von Mises is 0.897 MPa. Much lower than the elastic limit and therefore condition 1 is also fulfilled.

We can see that the results are very similar to those obtained in the previous simulation since the results of this simulation are much more accurate than those of the previous one.

Thanks to this second mesh, we obtain results that adjust much more to the reality and we can take for granted this model.

- **Fifth simulation: new module**

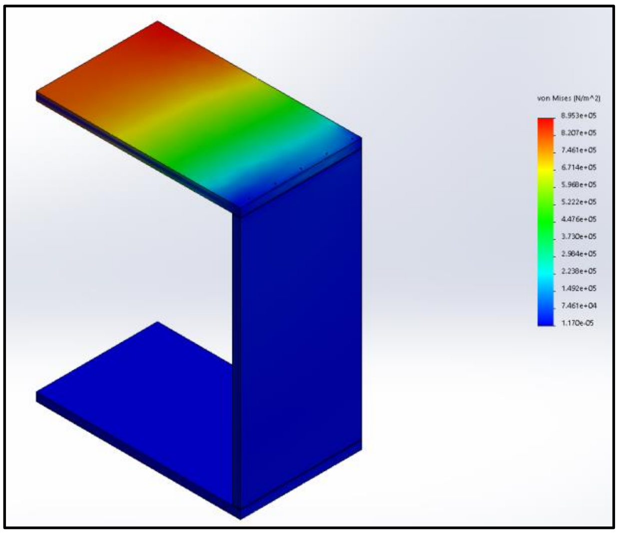
In this simulation the procedure of the third simulation was repeated, but changing the number of the blocks from 30 to 10.

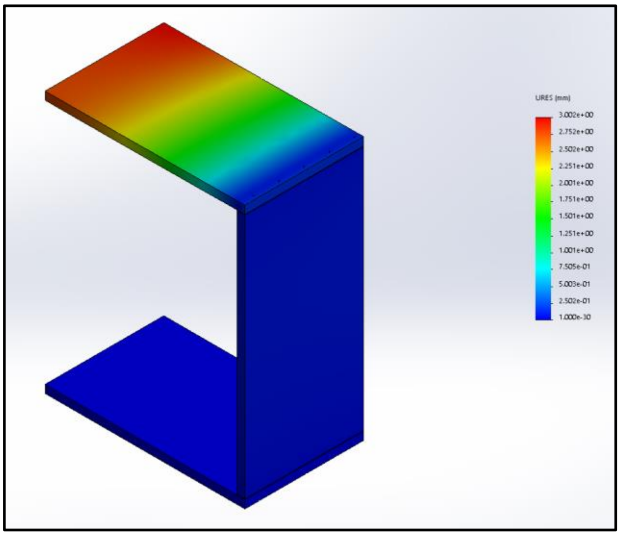
This configuration is composed of the following elements:

- 2 wood planks of 620x600x20mm
- 2 wood planks of 600x1010x20mm
- Module of 10 blocks

The wood used was **WOOD 1.**

After applying the study conditions explained, it was simulated and then the results are shown:





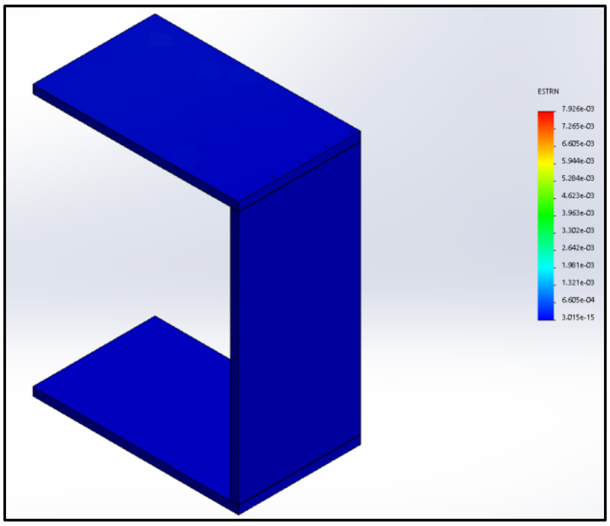


Image 37: 5th Simulation results

In this case it is seen that the condition of displacements is fulfilled. The maximum value, in the center of the upper board, is 3.002 mm.

As for the tension of Von Mises is 0.895 MPa. Much lower than the elastic limit and therefore condition 1 is also fulfilled.

Once the simulation is done, we see that the results obtained continue to meet the mechanical conditions so that the new optimal number of blocks is 10.

This simulation is performed to optimize the number of burdens that the module needs for its proper operation of the furniture.

- **Sixth simulation: mesh improvement**

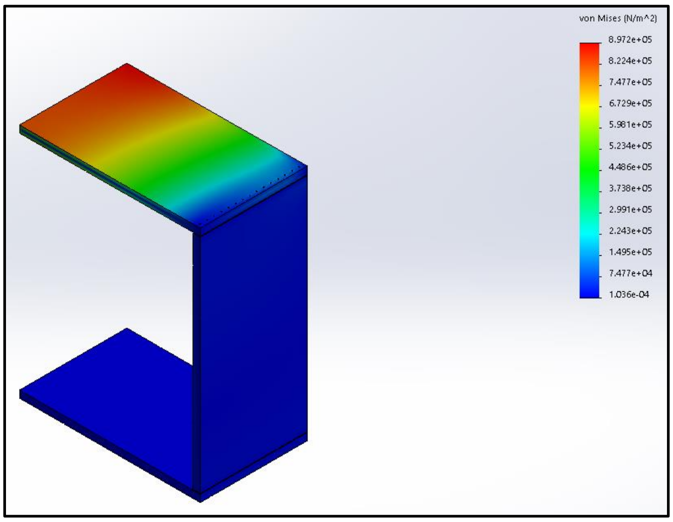
In this simulation, the previous procedure was repeated, but changing the type of mesh to obtain more accurate results.

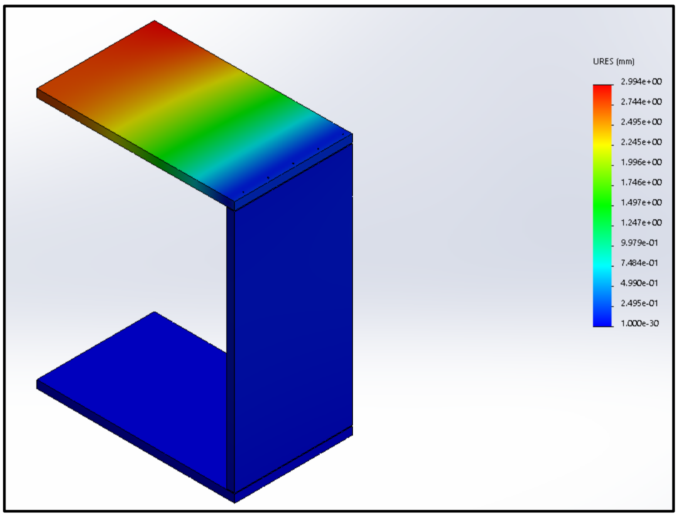
This configuration is composed of the following elements:

- 2 wood planks of 620x600x20mm
- 2 wood planks of 600x1010x20mm
- Module of 10 blocks

The wood used was **WOOD 1.**

After applying the study conditions explained, it was simulated and then the results are shown:





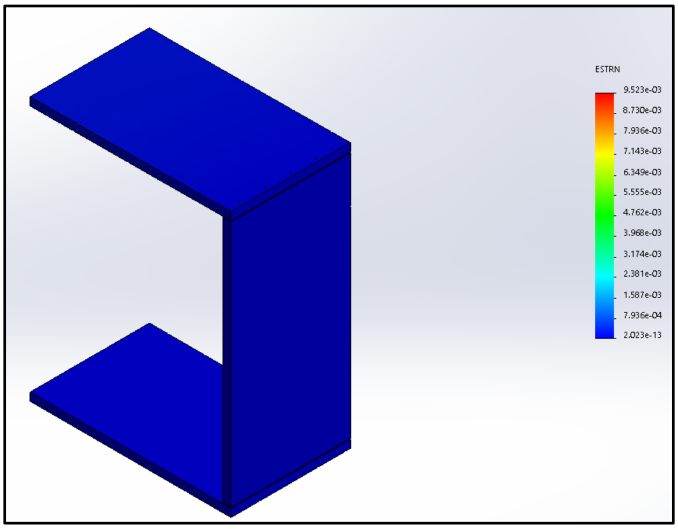


Image 38: 6th Simulation results

In this case it is seen that the condition of displacements is fulfilled. The maximum value, in the center of the upper board, is 2.994 mm.

As for the Von Mises tension is 0.897 MPa, much lower than the elastic limit and therefore condition 1 is also fulfilled.

It can be observed that the results are very similar to those obtained in the previous simulation since the results of this simulation are much more accurate than those of the previous simulation.

- **Seventh simulation: new module**

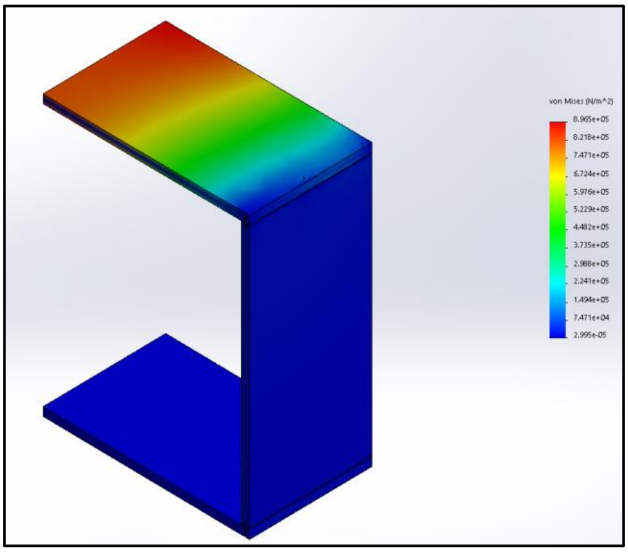
In this simulation the procedure of the fifth simulation was repeated, but changing the number of the blocks from 10 to 5.

This configuration is composed of the following elements:

- 2 wood planks of 620x600x20mm
- 2 wood planks of 600x1010x20mm
- Module of 5 blocks

The wood used was **WOOD 1.**

After applying the study conditions explained, it was simulated and then the results are shown:



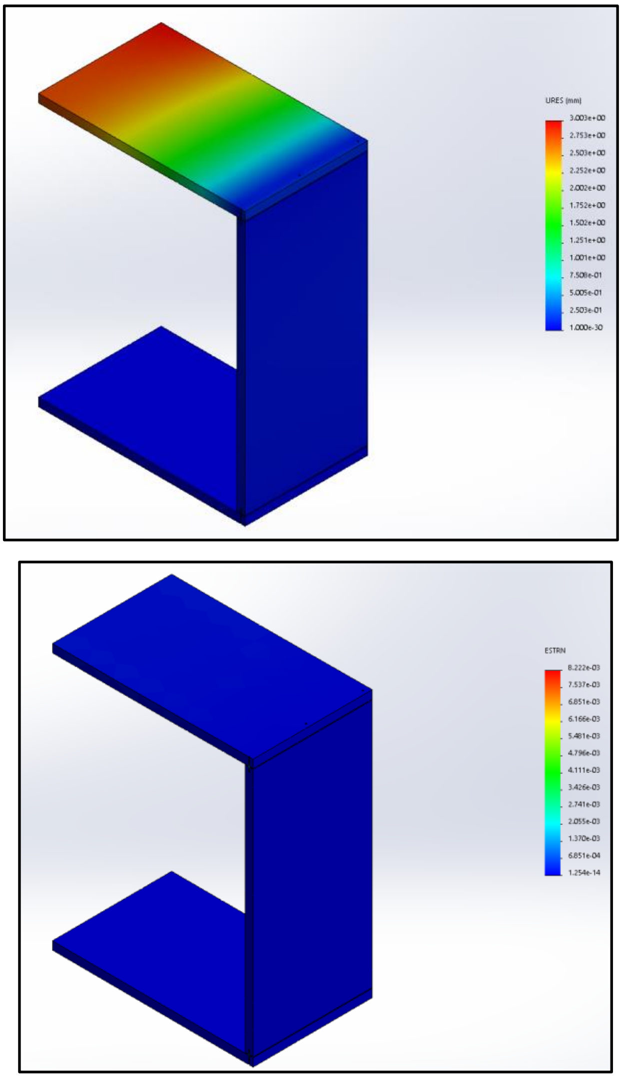


Image 39: 7th Simulation results

In this case it is seen that the condition of displacements is fulfilled. The maximum value, in the center of the upper board, is 3.003 mm.

As for the Von Mises tension is 0.897 MPa, much lower than the elastic limit and therefore condition 1 is also fulfilled.

Once the simulation is done, it is seen that the results obtained meet the mechanical conditions so that the new optimum number of blocks is 5.

- **Eighth simulation: mesh improvement**

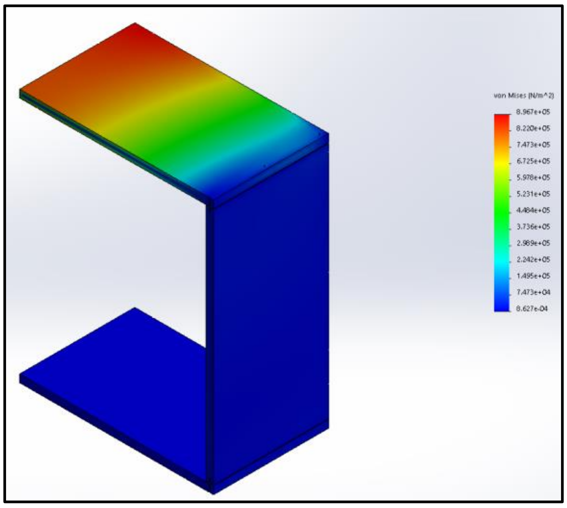
In this simulation, the previous procedure was repeated, changing the type of mesh to obtain more precise results.

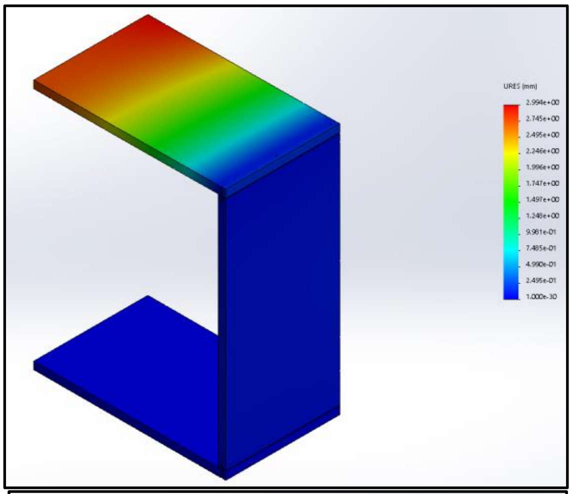
This configuration is composed of the following elements:

- 2 wood planks of 620x600x20mm
- 2 wood planks of 600x1010x20mm
- Module of 5 blocks

The wood used was **WOOD 1.**

After applying the study conditions explained, it was simulated and then the results are shown:





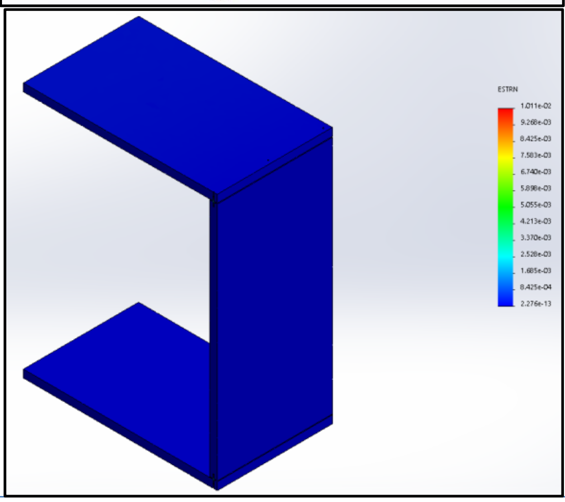


Image 40: 8th Simulation results

In this case it is seen that the condition of displacements is fulfilled. The maximum value, in the center of the upper board, is 2.994 mm.

As for the Von Mises tension is 0.897 MPa, much lower than the elastic limit and therefore condition 1 is also fulfilled.

We see that the results are very similar to those obtained in the previous simulation since the results of this simulation are much more accurate than those of the previous simulation.

- **Ninth simulation: new module**

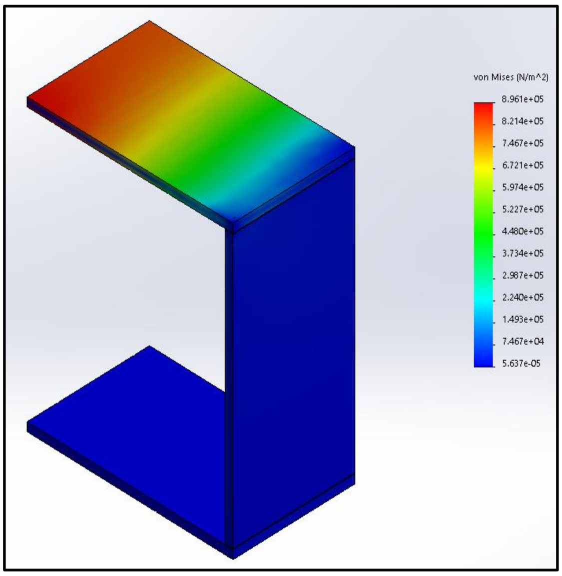
In this simulation the procedure of the fifth simulation was repeated, but changing the number of the blocks from 5 to 3.

This configuration is composed of the following elements:

- 2 wood planks of 620x600x20mm
- 2 wood planks of 600x1010x20mm
- Module of 3 blocks

The wood used was **WOOD 1.**

After applying the study conditions explained, it was simulated and then the results are shown:



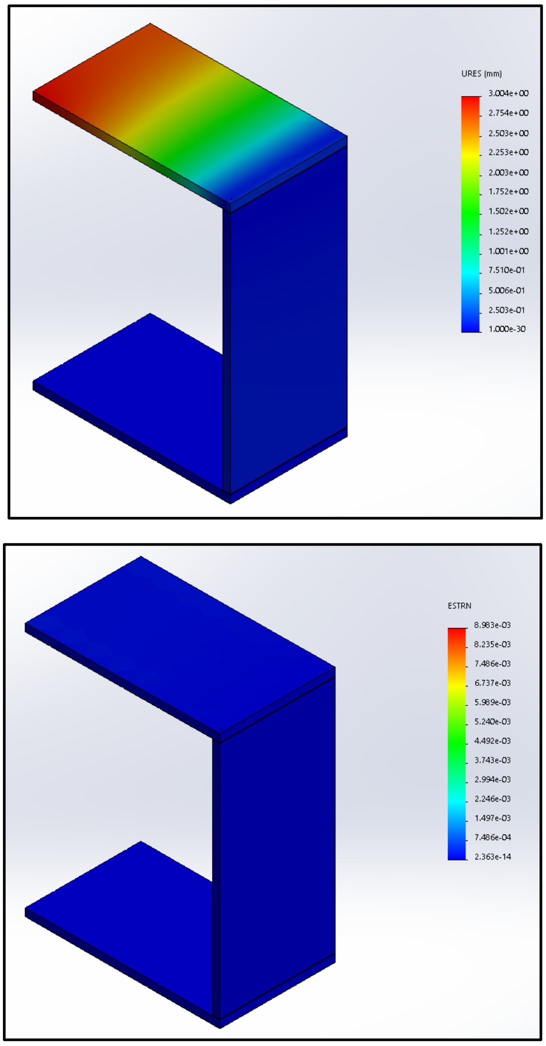


Image 41: 9th Simulation results

In this case it is seen that the condition of displacements is fulfilled. The maximum value, in the center of the upper board, is 3.004 mm.

As for the Von Mises tension is 0.895 MPa, much lower than the elastic limit and therefore condition 1 is also fulfilled.

Once the simulation is done, we see that the results obtained meet the mechanical conditions so that the new optimum number of blocks is 3.

- **Tenth simulation: mesh improvement**

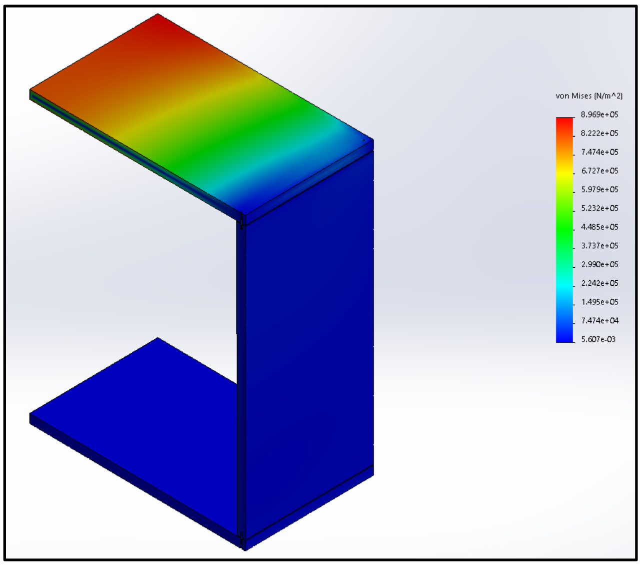
In this simulation, the previous procedure was repeated, but changing the type of mesh to obtain more accurate results.

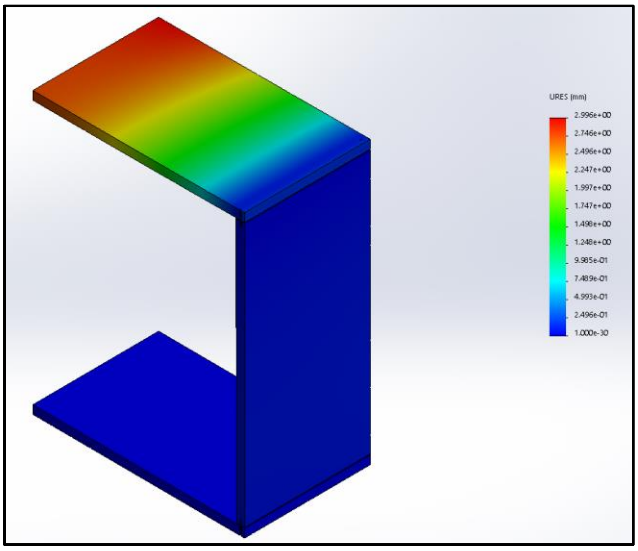
This configuration is composed of the following elements:

- 2 wood planks of 620x600x20mm
- 2 wood planks of 600x1010x20mm
- Module of 3 blocks

The wood used was **WOOD 1.**

After applying the study conditions explained, it was simulated and then the results are shown:





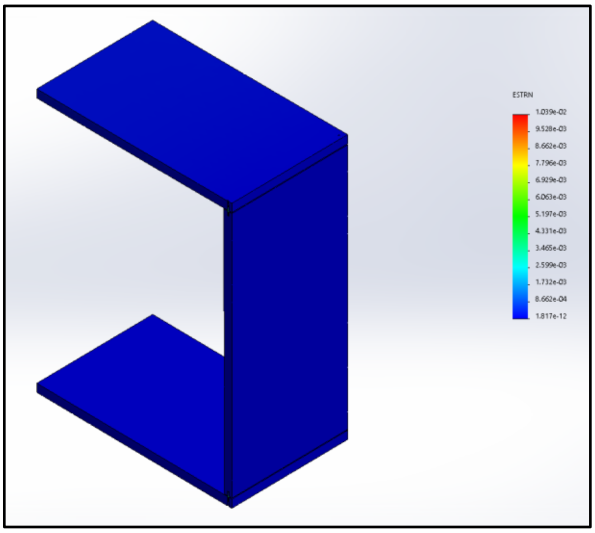


Image 42: 10th Simulation results

In this case it is seen that the condition of displacements is fulfilled. The maximum value, in the center of the upper board, is 2.996 mm.

As for the Von Mises tension is 0.897 MPa, much lower than the elastic limit and therefore condition 1 is also fulfilled.

We see that the results are very similar to those obtained in the previous simulation since the results of this simulation are much more accurate than those of the previous simulation.

Before speaking of the final decision on which is the optimal frequency of the blocks and which is the optimal thickness, other items of the shelf are presented.

5.3.5 Other items of the shelf

Once the optimal number of blocks was found, another part of the project started. Designing three elements, complements for the piece of furniture, inspired in the same idea of not using screws or any similar element. They are presented as it follows.

5.3.5.1 Union of the bar (hanger)

Another union of the furniture that wants to be taken into account is the union of the bar - hanger. All the unions studied so far between the planks have been solved with the module in I, explained in point 5.3 and validated in point 5.4.1. The union of the bar with the planks on its side does not seem to be input that can be solved with the module in I.

The image below shows the area where the bar is supposed to go, inspired by the furniture of IKEA.

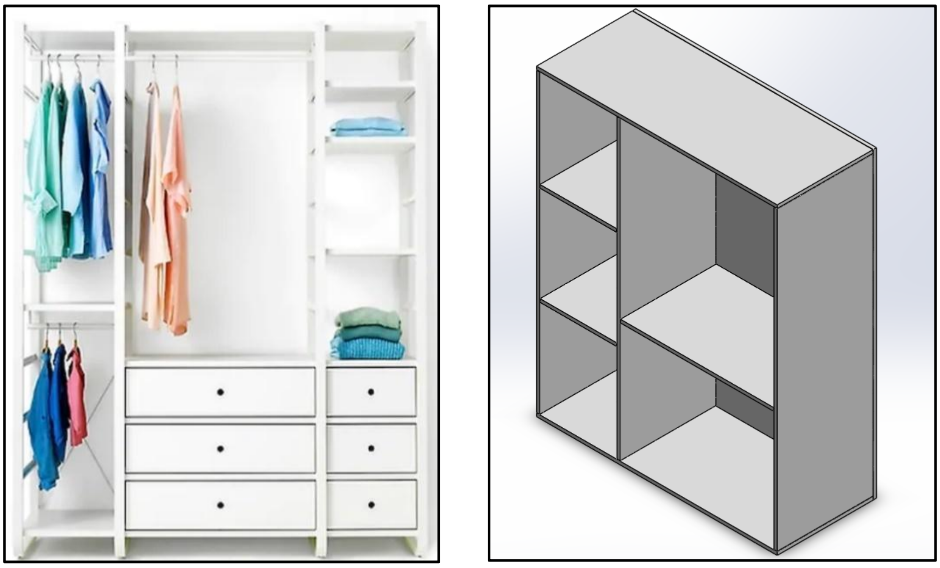


Image 43: Image that shows the furniture of study. In the upper right zone is where the bar will be located.

The idea of solving the union of the bar with the wooden planks is not defined. What is known for sure is that it wants to be inspired by the module in I that has been used to solve all the unions on the shelf. For example, we could try to make a circular module with the blocks arranged in a specific way and try to support the weight of the bar and the additional one.

Having said that, below is a detailed study of the state of the art. From this study, it will be determined how to deal with this union.

5.3.5.1.1 State of the art: Proposals that are in the market

In the market there are a lot of bar proposals. There are of different sizes, different materials, different colors, different structures, with different applications ... Below is a small part of what is on the market. It is the state of the art.

Design 1: Extensible stainless steel telescopic bar for curtain.

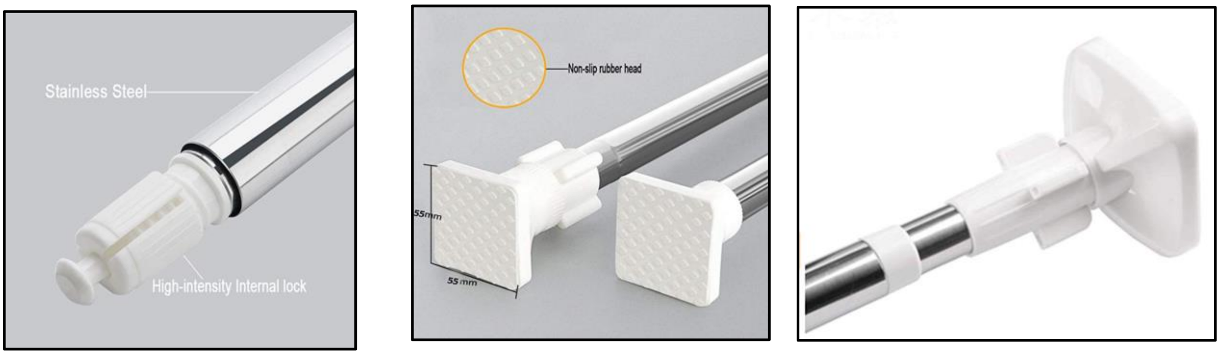


Image 44: 1st example of bar

Size: 88-160cm

Price: 20,88€

Material: Stainless steel

Description:

- No tools, no drilling, no damage: due to its scientific design, this product can be assembled quickly.
- Spring tension rod: made of high quality thick stainless steel and ABS plastic, this product is rust resistant and durable.
- Rich Functionality: This shower curtain rod can be used not only in a bathroom, but also as a bar to hang in a closet, a balcony or even a clothing store to store or display clothes.

Design 2: adjustable locker; extensible bar

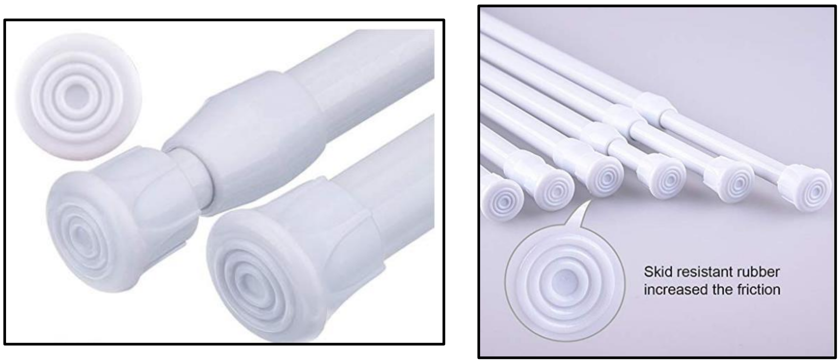


Image 45: 2nd example of bar

Size: Adjustable from 15.7 inches to 27.5 inches (40-70 cm), diameter of 0.5 inches

Price: 12,99€ (5 units)

Material: Plastic ABS

Description:

- Easy to install and remove, On both ends of the use of non-slip rubber,
- Each tension bar can support 2 to 4 kg.
- Without tools, without screws, glue or holes, without damage to the walls or doors and windows, it is only necessary to adjust the length to get stuck between the 2 walls, without other fixings

On the studio furniture, it would be as it follows:

Image 46: Bar on the furniture

Design 3: Set of 2 adjustable ceiling supports - Bronze

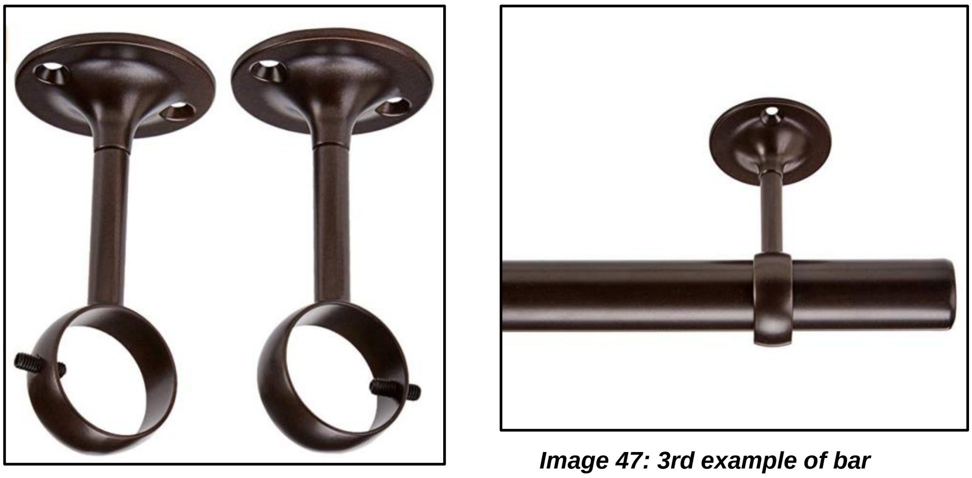


Image 47: 3rd example of bar

Size:

- Rings: Suitable for bars up to 2.5cm in diameter
- Supports: They measure 8.9 cm long and have a base of 4.7 cm in diameter.

Price: 11,99€ (bar non included)

Material: Durable cast metal and bronze finish.

Description:

- The set of 2 supports for curtain rod are mounted securely to the ceiling or wall.
- Up to 4.9 kg of weight capacity per support.
- Ideal for creating room dividers or hanging curtains from the ceiling to the wall.
- Mounting material included.

The bar can be bought by itself.

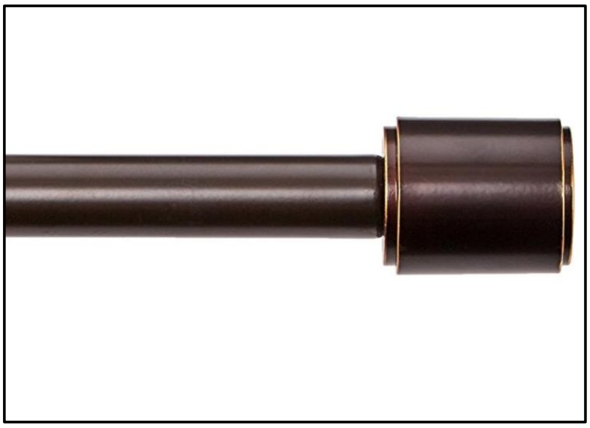


Image 48: Wooden bar

Size: Diameter of 2,5 cm

Price: 22€

Material: Wood

Description:

-stretches from 182 to 365 cm.

-The bar is capable of supporting up to 9.9kg.

Design 4: Wardrobe bar

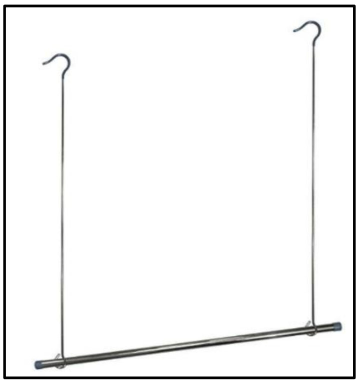


Image 49: 4th example of bar

Size: 75 x 85 cm

Price: 16€

Material: -

Description:

- Ideal for all kinds of furniture
- Hooks for protection

Design 5: WINOMO Curtain Bar Curtain Bar Tension Bar Extendable Bar


Image 50: 5th example of bar

Size: Aprox. 57 x 3 x 3 cm (extensible to 103cm)

Price: 9,99€

Material: Stainless steel

Description:

- Easy to assemble, it is quickly installed on vertical panels in a cabinet with hardware included.
- The practical application on many occasions, houses, clothing stores, laundries or simply places where there are clothes must be hung

Color: Silver

On the furniture it would look like this:

Image 51: Metallic bar

So far, there are 5 designs that are currently on the market. Below is an analysis of these adapting to the need for this project; Solving the union of the bar-hanger with the sideboards.

5.3.5.1.2 State of art analisis

In 5.3.5.1.1, 5 designs with different characteristics have been shown for each one of them.

Below is a series of properties / concepts that the module wanted to design has. Depending on how much the designs of the state of the art approach to the design wanted, a value between 0 and 5 will be assigned.

Properties/Concepts	**Design 1**	**Design 2**	**Design 3**	**Design 4**	**Design 5**
Lightness	2	3	3	2	2
Cost	2	4	4	3	4
Original/Different	3	3	3	4	3
Aesthetics	1	2	4	4	1
Non use of screws	5	5	0	5	5
Reciclability	3	2	3	2	3

Table 5: Evaluation about some properties

The previous table aims to quantify as precisely as possible, what you want the design to have and what is not.

Regarding the lightness, the idea for the shelf that is being designed would be to use a wooden bar. Ideally the same type as that of planks.

In this way, the aesthetics would be resolved. What would not be too good for aesthetics would be, for example, to use a Design 1 or Design 2. Anyway, it should be said that if this extensible element was made of wood, then it would not be aesthetically so ugly. The same goes for Design 5.

Regarding originality, design 3 is the ideal. In any case, it is discarded because it requires keys to fix it on the top. On the other hand, the idea of design 4 putting a bar under the other is not entirely bad. Anyway, maybe it does not fit the dimensions of the shelf that is proposed.

The cost depends mostly on the material. As the idea is to make it of wood, we do not believe that the cost is a disadvantage. Perhaps, however, the cost will increase with the unions.

Speaking of recyclability, with wood there is no problem. The designs of plastic (ABS) or steel are more difficult to recycle but it is well done nowadays.

The non-use of keys is one of the premises of this project. Except design 3, which requires it, the rest meet this requirement.

5.3.5.1.3 Designs and simulations of the circular union module

DESIGN 1

Below is a first design, inspired by the union in I studied previously.

It seems very complicated to solve this union bar-planks with a union in I Vertical. Therefore a first design is made that is shown below, with a circular module and horizontal connection.

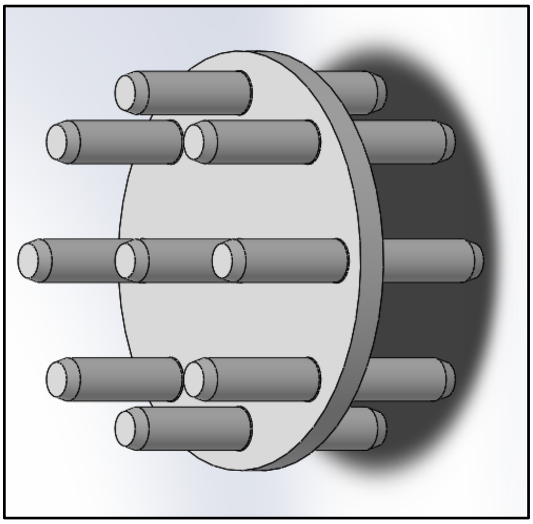


Image 52: Module of circular blocks

The blocks are arranged at 45 degrees among them, and one central. The dimensions of the blocks are the same as the joints shown in point 5. In the same way, the thickness of the circular platform that supports the pins is the same as that of the vertical module I.

SIMULATION 1

The procedure followed in the first simulation of the bar is shown below.

The elements used are those detailed below.

· Bar

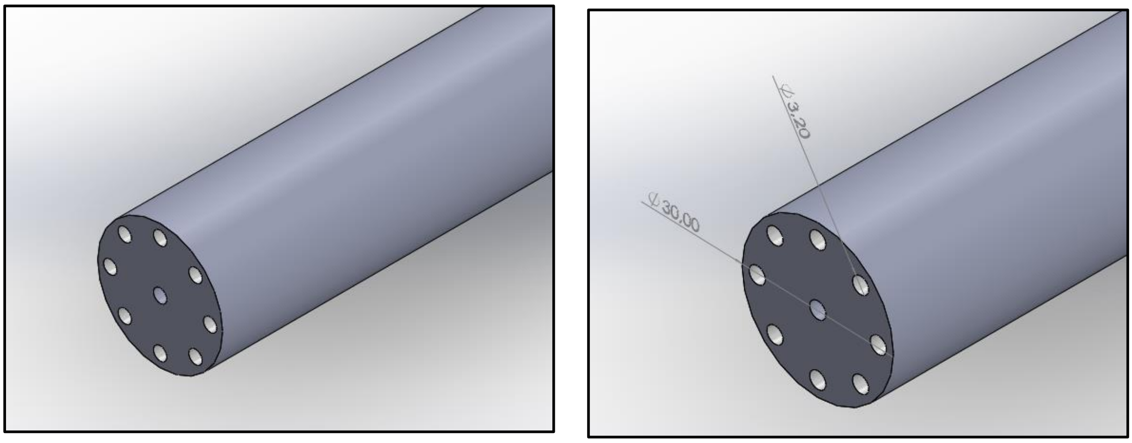


Image 53: Holes in the bar and dimensions

- The bar's length is 100 mm.
- Circular union
- Wooden planks with holes for blocks

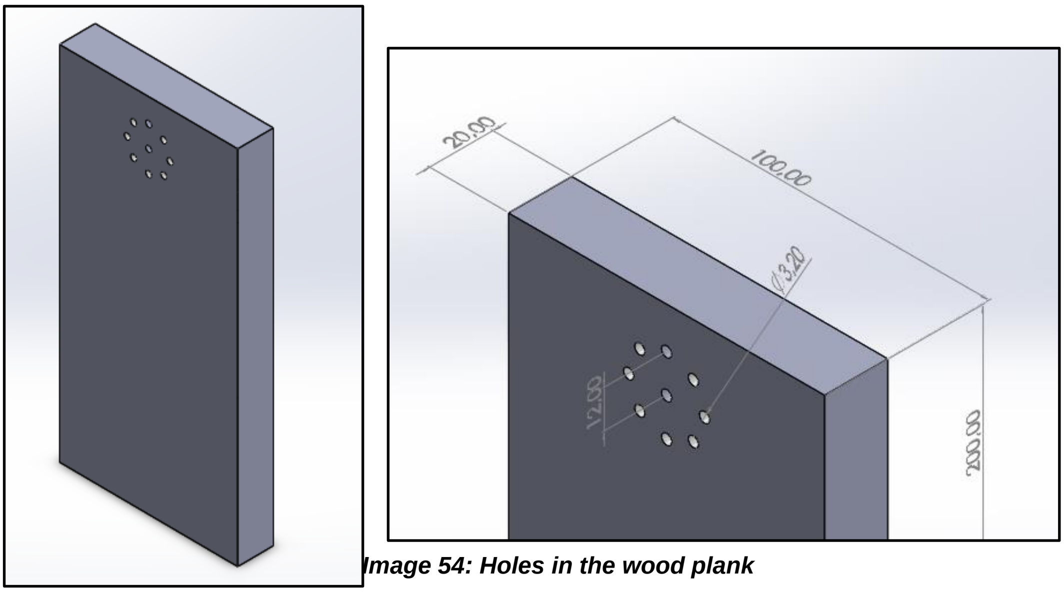


Image 54: Holes in the wood plank

The dimensions of the holes are the same as those of the pins, because they fit together.

Regarding the dimensions of the boards, they are not the same since in this way the number of elements in the mesh could be reduced. However, as it is a fixed part, it does not alter the final result.

To make the mesh, 2 mesh controls were first made. One for circular junctions, and the other for the bar. It was necessary to do it for the two elements since both have very small elements (pins and holes for the blocks)

As per the mesh of the planks, it is not to fine since it was considered that it was not the purpose of the study. Below is a photo of the mesh.

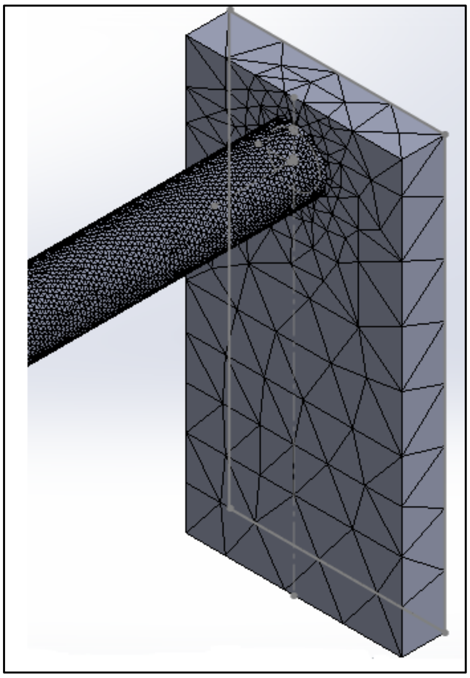


Image 55: Image of the assemble with the meshing

The material of the circular joints is the ABS, and those of the planks the final wood used in the simulations.

Below is an image of the assembly made with the force applied, of 50 N.

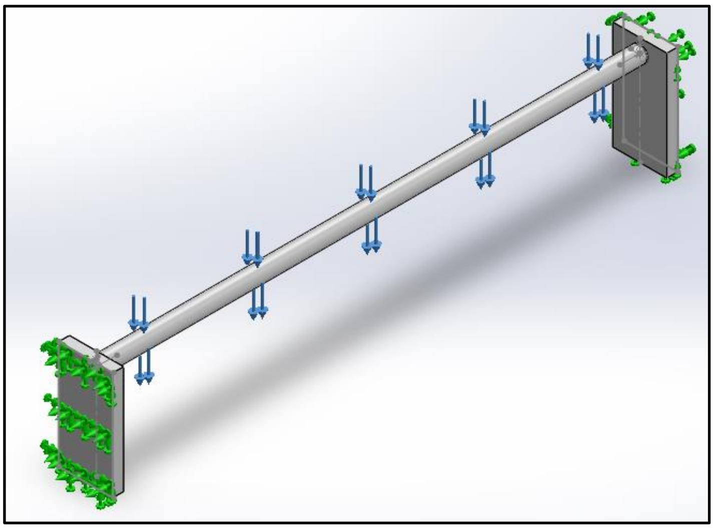
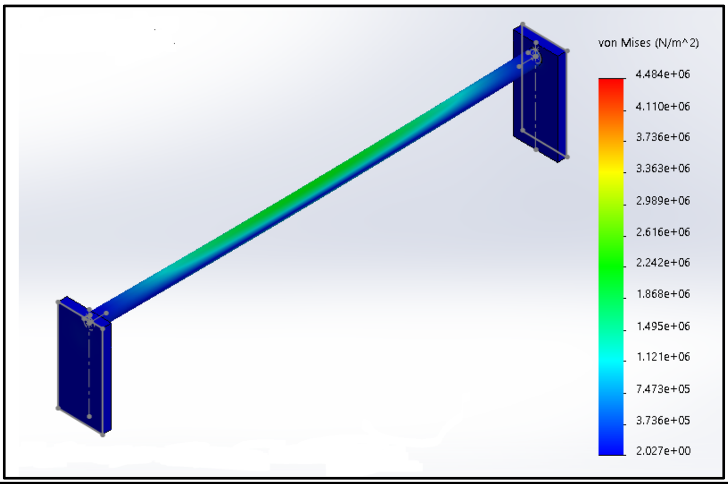
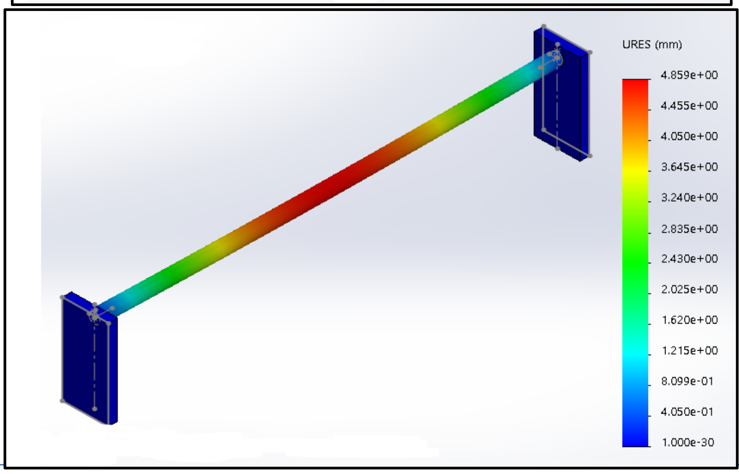


Image 56: Image with the conditions of the simulation

Since the meshing is very precise in the circular joints and the bar, the simulation has taken about an hour. The number of degrees of freedom was 2 million, and the number of elements 714 thousand.

The results are shown below.





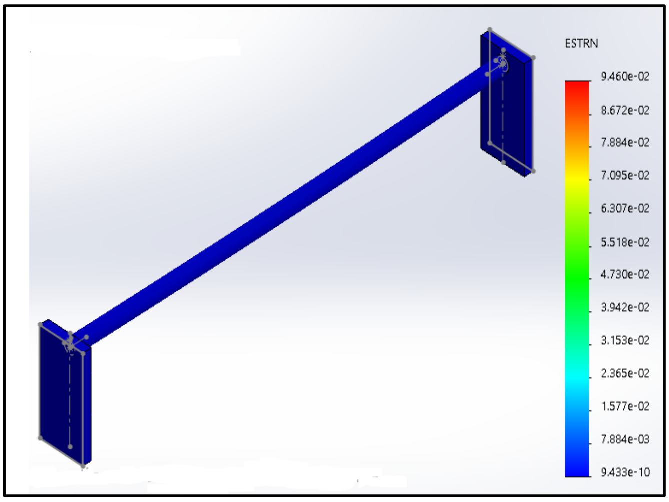


Image 57: Results of the 1st bar simulation

As for the Von Mises stress, in the center of the bar is around 2.616 MPa. This value is much lower than the elastic limit of the material (wood) and therefore it will not cause problems. The maximum value indicated by the graph is 4,484 MPa. This one is in the unions, more specifically the blocks. Below is an enlarged image of the highest stress area.

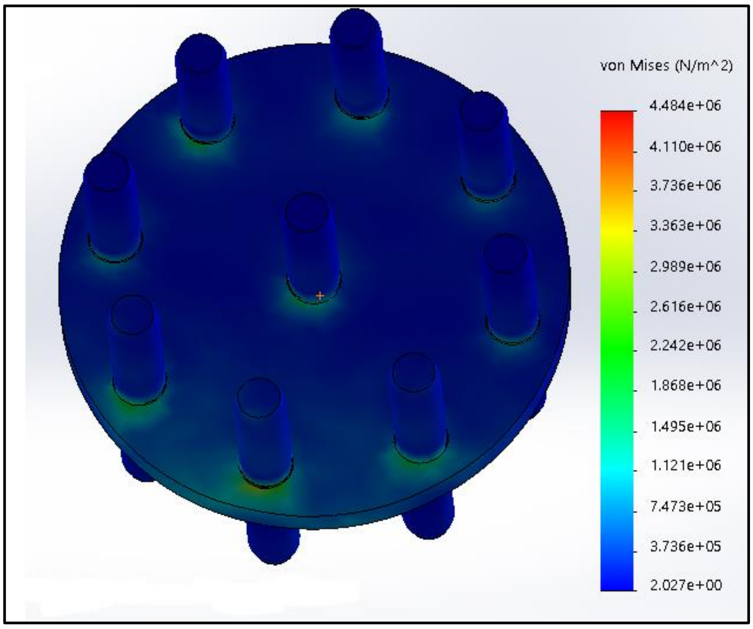


Image 58: Local view of the Von Mises stress

The maximum Von Mises stress is in the small slot at the base of the blocks. Although much lower than the elastic limit of the material, it will be taken into account to face the next design. On the other hand, a slightly higher tension can be seen in the lower part of the union. Anyway, the next design will keep the symmetry to simplify the assembly.

Regarding the displacement, this is maximum, with a value of 4,850 mm, in the center of the bar. It looks like a logical result and meets the conditions explained in point 5.

In any case, it is a displacement close to 5mm, a limit that has been imposed on this project. Therefore, it will be tried in the next design to reduce it a bit.

DESIGN 2

Once the first design has been made and the corresponding simulation has been done, it has been decided to try to reduce the maximum displacement of the center of the bar. In the same way, it has been decided to reduce the tension in the pius. To do this, a new circular union with more blocks, designed at 60 degrees among them, has been designed. Below is the union.

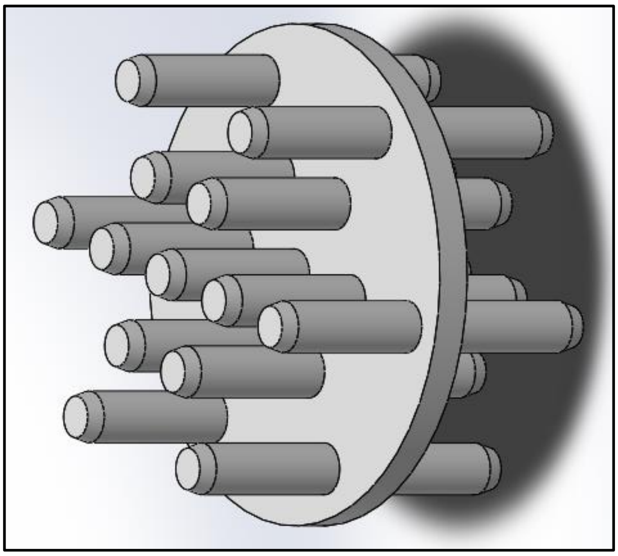


Image 59: 2nd design of the circular module

It is believed that adding enough blocks will reduce the Von Mises stress in all of them.

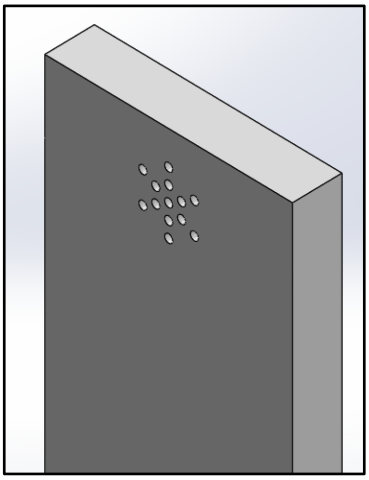
SIMULATION 2

The elements used for the simulation are the following:

- Bar: described in the previous simulation

- Circular Union

- Wooden boards with holes for the blocks



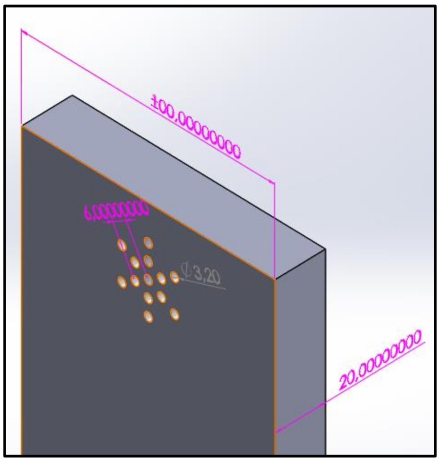
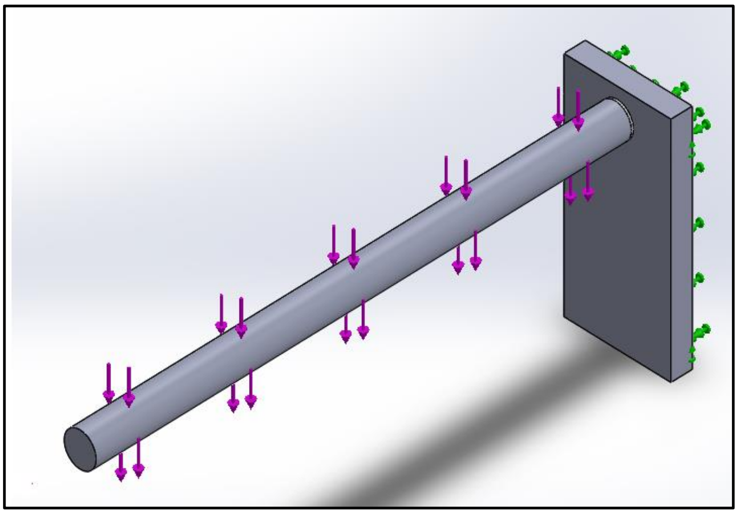


Image 60: Holes in wood plank - 2nd design

Although the same mesh has been used as in the first simulation, in this one symmetry has been used. Since this is a symmetrical piece, this has significantly reduced the number of degrees of freedom, elements and consequently simulation time. 245 thousand elements, 1 million GLL (before 2 M) and 40 'to solve the simulation.



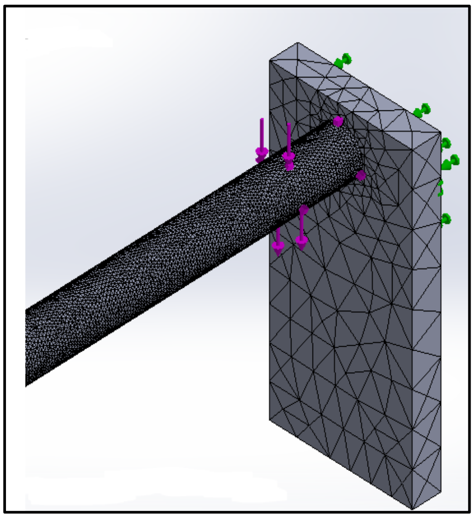


Image 61: Image with conditions of the 2nd simulation and mesh

Image of the symmetric figure, with an applied force of -25 N. (50 N without symmetry)

The materials used were the same as the first simulation.

As it follows, the results are shown:

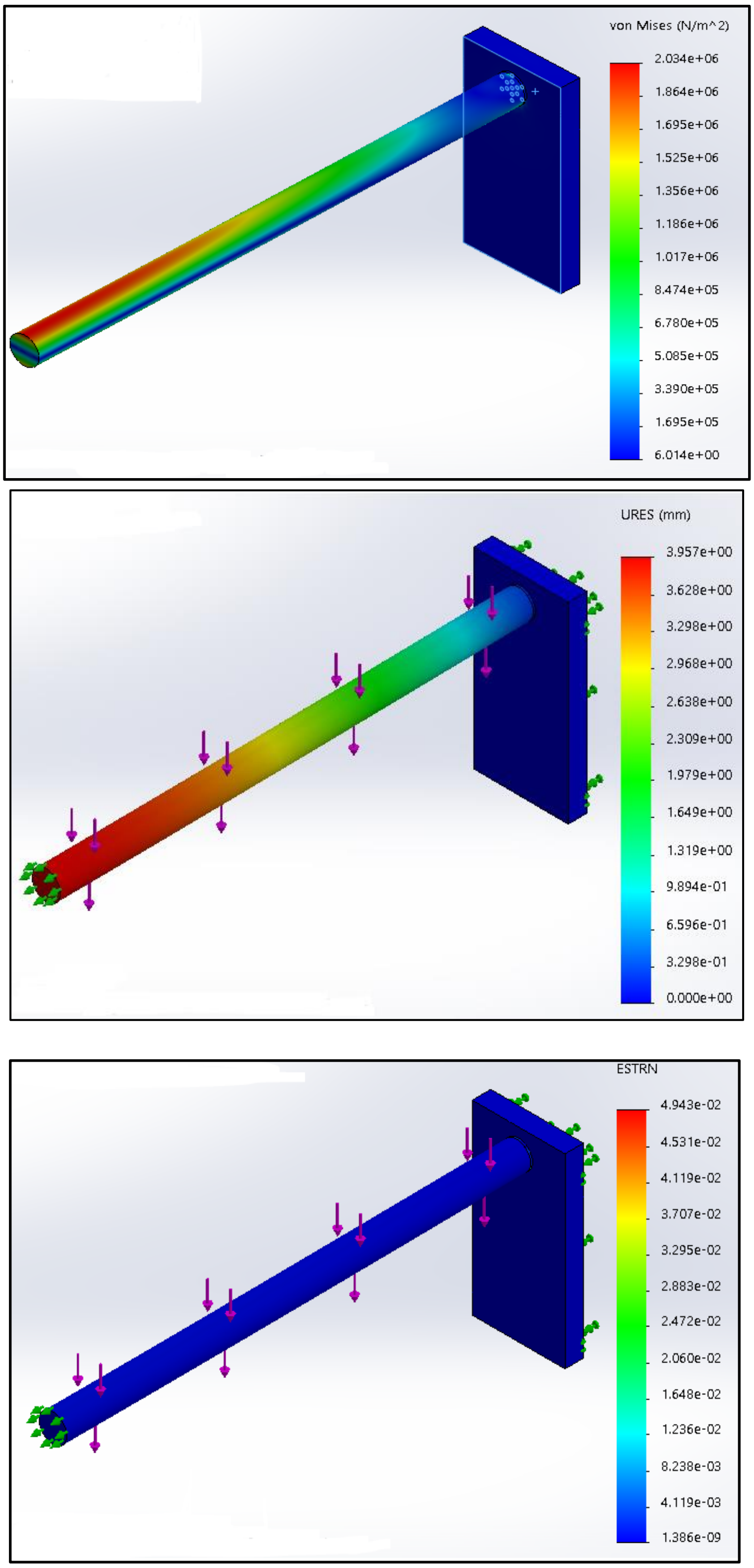


Image 62: Results of the 2nd bar simulation

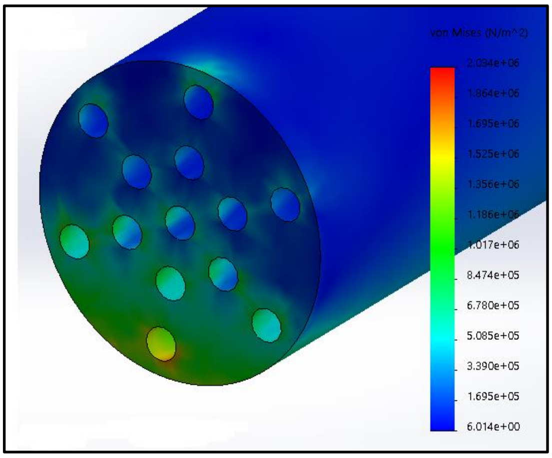


Image 63: Local view of the Von Mises stress

As for the Von Mises stress, the maximum value has been reduced to 2,034 MPa, and this time it is located in the center of the bar. Because this value is smaller than the elastic limit, the structure would hold. As for the tension in the joining holes with the blocks, it can be seen that it has also been reduced. On the contrary, it has focused mainly on the hole below. For the next design, we will try to add more blocks to the bottom to minimize the Von Mises stress.

Regarding the displacement of the set, it has been reduced by 1mm, up to 3,957 mm. This displacement also fulfills the condition of displacements but can obviously be improved.

DESIGN 3

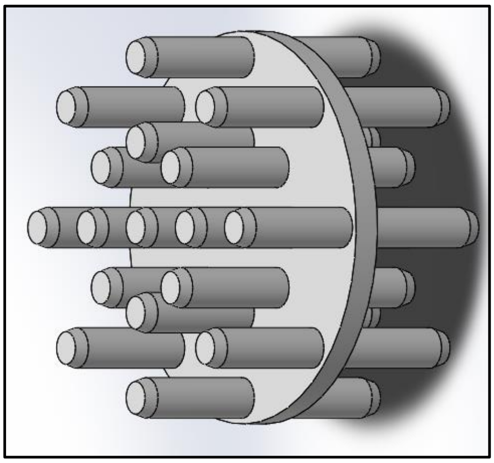


Image 64: 3rd design of the circular module

Next, a third design is proposed to solve the joining of the bar-hanger. The criteria has been to increase even more the number of little blocks to try to reduce Von Mises' tension to all of them. It is also expected that the overall displacement of the bar will also be reduced slightly.

SIMULATION 3

The elements used for the simulation are the following:

- Bar: described in the previous simulation

- Circular Union

- Wooden planks with holes for blocks:

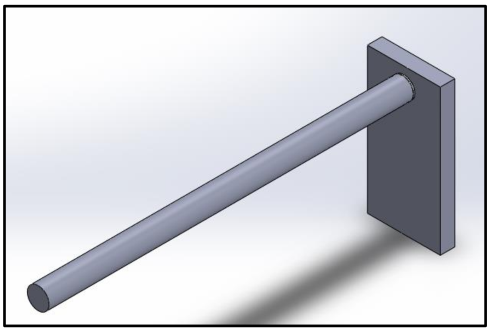
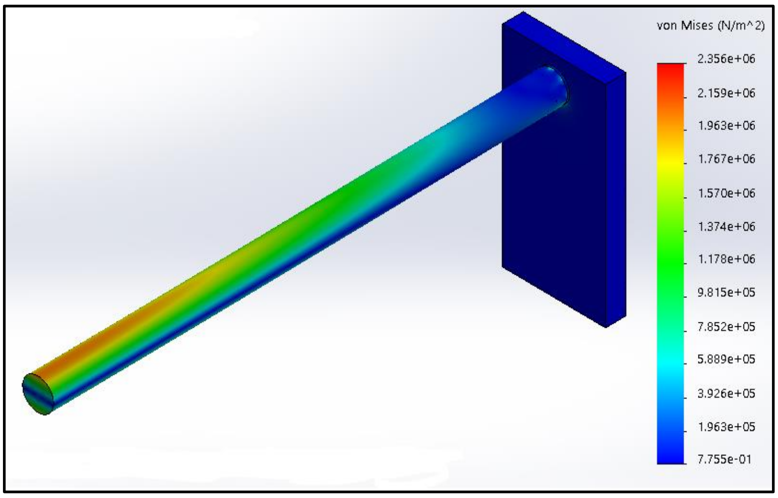
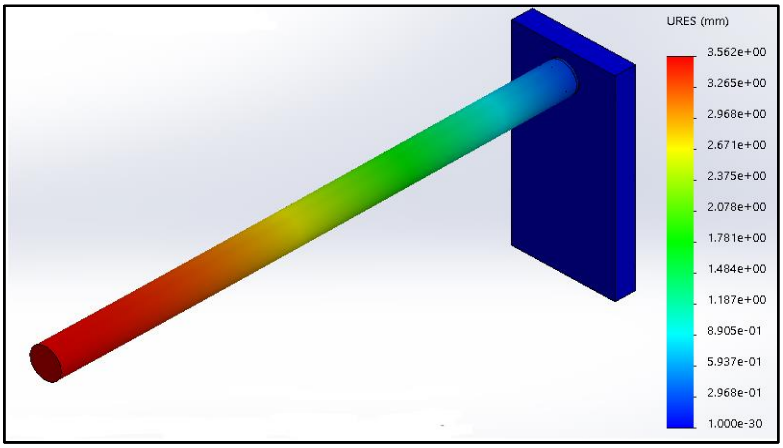


Image 65: Assembling of the bar

The mesh and the material used are the same as in the previous simulations.

The results are shown below.





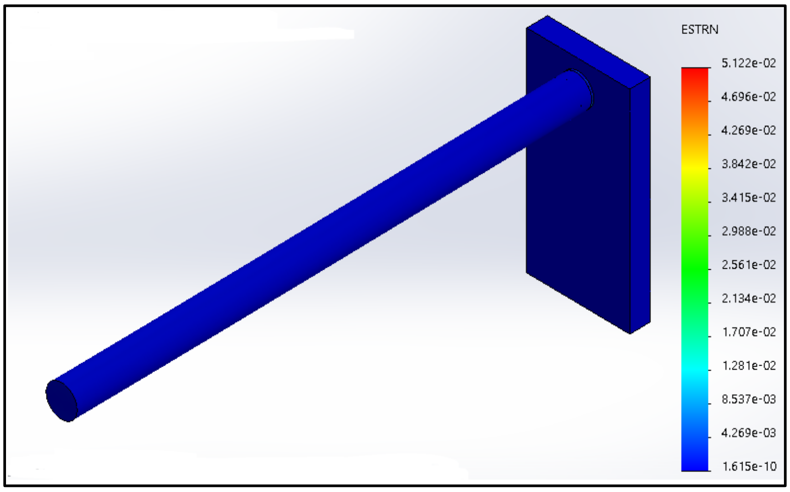
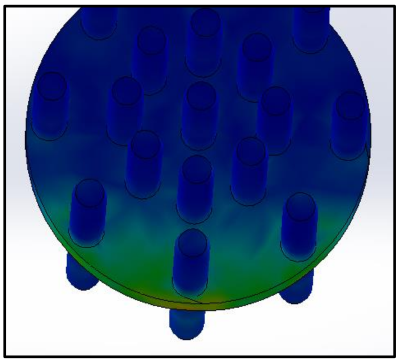


Image 66: Results of the 3rd bar simulation

The global maximum displacement has been reduced to 3,562 mm, slightly lower than that of design 2.

As for the Von Mises stress, the maximum value is 2,356 MPa, and it is in the center of the bar. Since this value is lower than the elastic limit, this model could serve as a solution.



As far as the stress is concerned, they do not seem to suffer almost anything, except those on the bottom. In any case, it is sufficiently well distributed and there are no exaggerated overstress.

Image 67: Local view of the Von Mises stress

DESIGN 4

Although, in terms of structure, the proposed design would hold, it must be said that it presents a clear limitation. Since the bar must go between two boards, so that the system works as it should, a table should first be placed (left for example), then the joints and bar and finally fit the right board. It would not be possible to add this accessory once the furniture has been assembled.

That's why, and with the idea of solving this problem, a new design is proposed. With this, the bar-hanging accessory could be added once the shelf is assembled.

Below is the new design:

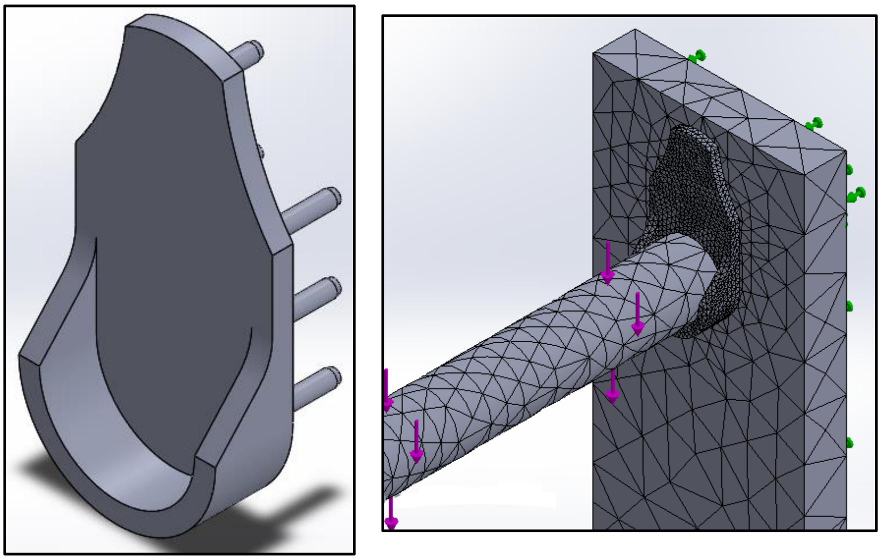


Image 68: 4th design and mesh for the simulation

The following design contains a slot in the form of a tube to fit the bar. The inner diameter of the tube and the one of the bar are the same, therefore they fit perfectly. On the other side, and following the line of this project of not using screws, a series of blocks have been set.

SIMULATION 4

Since the point of study is the designed union, a mesh control of size 2 mm has been applied there. In the image the mesh is shown.

To speed up the simulation, symmetry has been applied. The materials used are identical to those of the previous simulation. The force applied, too.

The results are shown below.

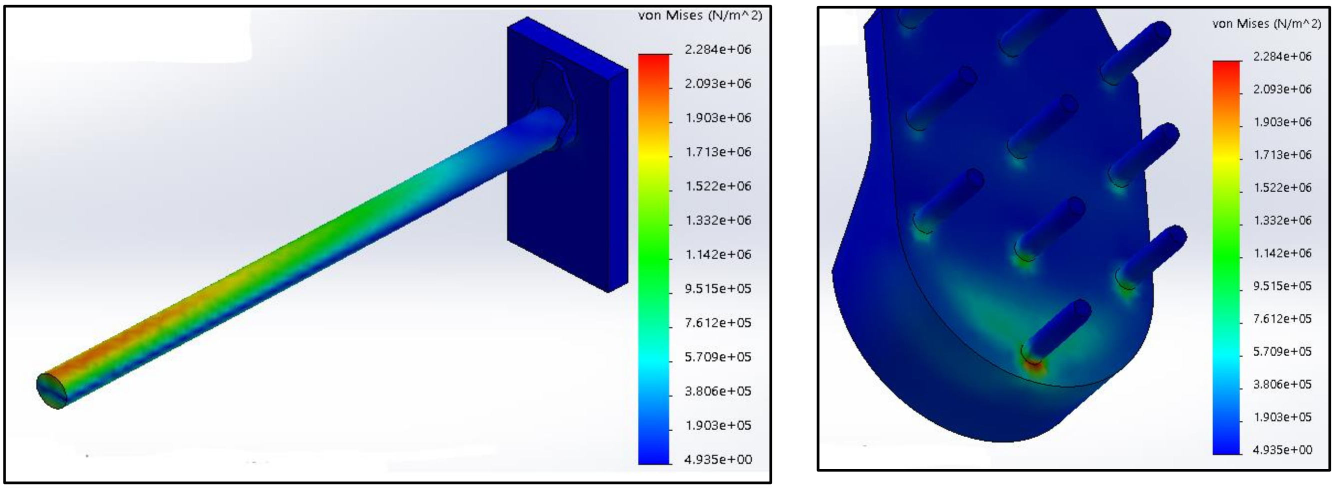


Image 69: Results of the 4th bar Simulation

As for the Von Mises stress, the maximum has a value of 2,284 MPa, less than the elastic limit of the material. The center of the bar suffers, but more does the lower block. For the next and final design, more blocks will be added to the bottom.

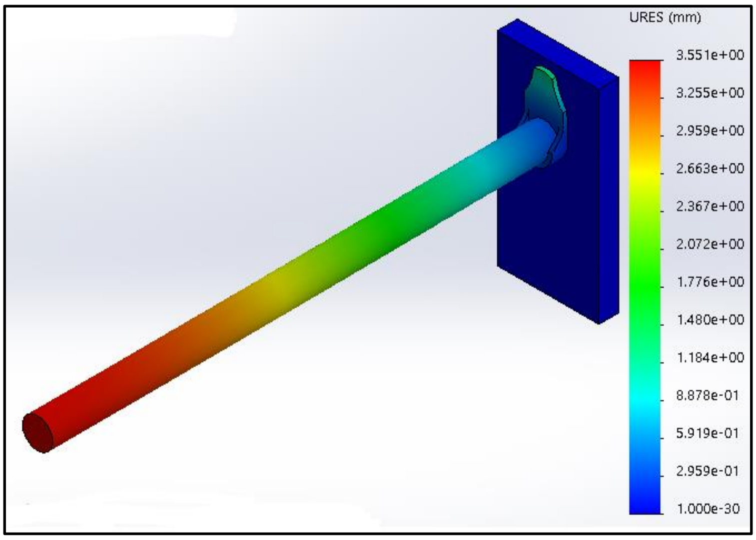


Image 70: Displacements of the simulation

As for the maximum displacement, it is located in the center of the bar. It is less than 5mm and therefore complies with the mechanical condition imposed on this project.

The upper part of the union has about 1.776 mm displacement. In the next design, we will try to reduce this separation.

FINAL DESIGN

Considering the analysis of previous results, the final proposal has been designed.

It has become a little more compact to avoid displacements in the upper area.

More blocks have been placed on the lower semicircular zone.

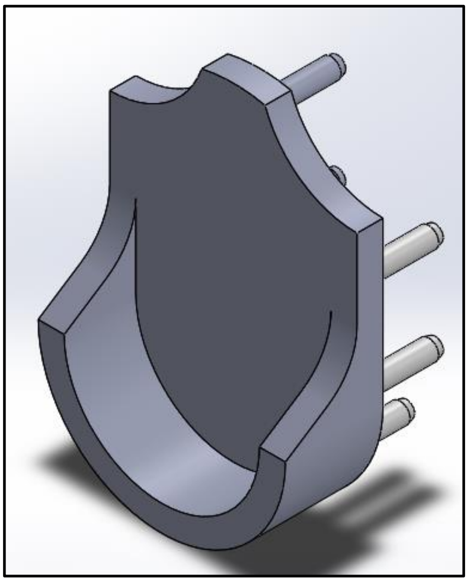
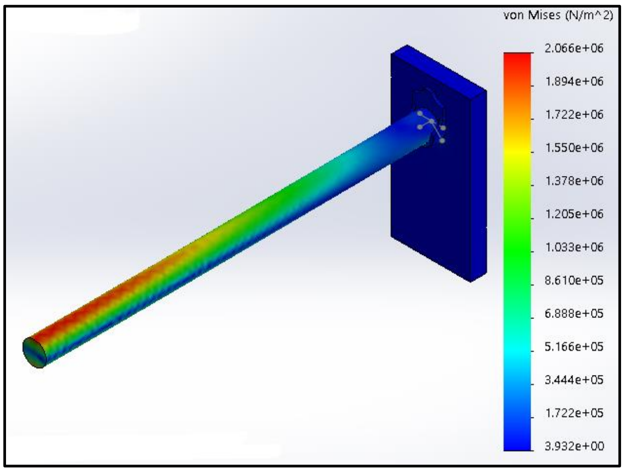


Image 71: Final design of the circular module

FINAL SIMULATION

With the same conditions as in the fourth simulation, the study was carried out. The results are shown below.



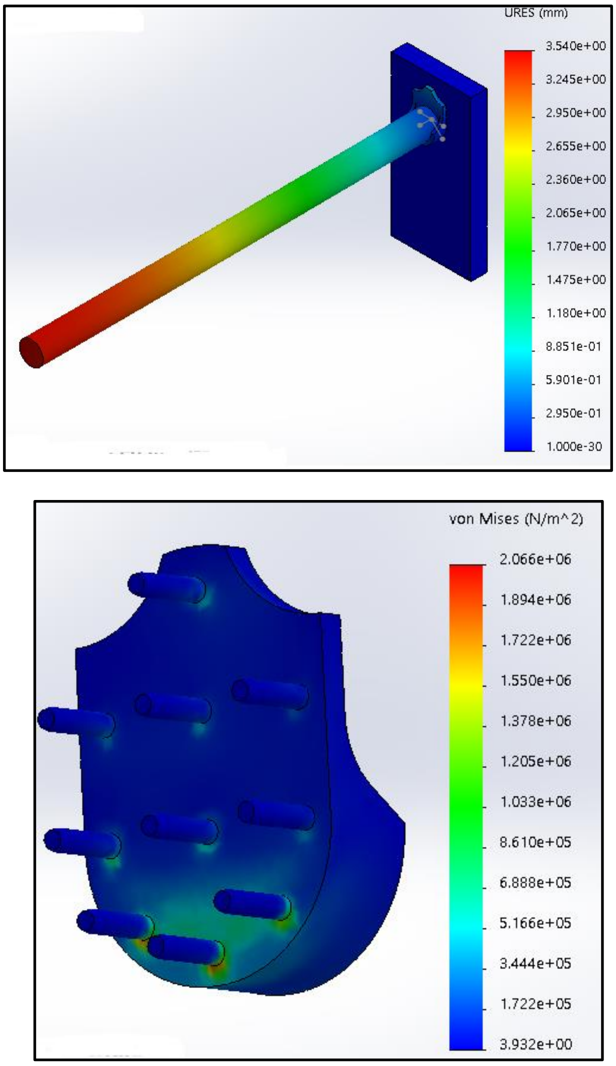


Image 72: Results of the final bar simulation

The Von Mises stress has been maintained with respect to the fourth simulation, with a maximum value of 2,066 MPa.

The overall maximum displacement has also remained constant with respect to the fourth simulation.

The fact of having added more blocks to the lower semicircle has produced a better distribution of the stress in that area.

5.3.5.2 Special union: continuous

Another application that has been thought to be necessary throughout the useful life of the furniture is a union that serves to enable the user to add planks based on their needs. The union designed to solve this need is the one presented below.

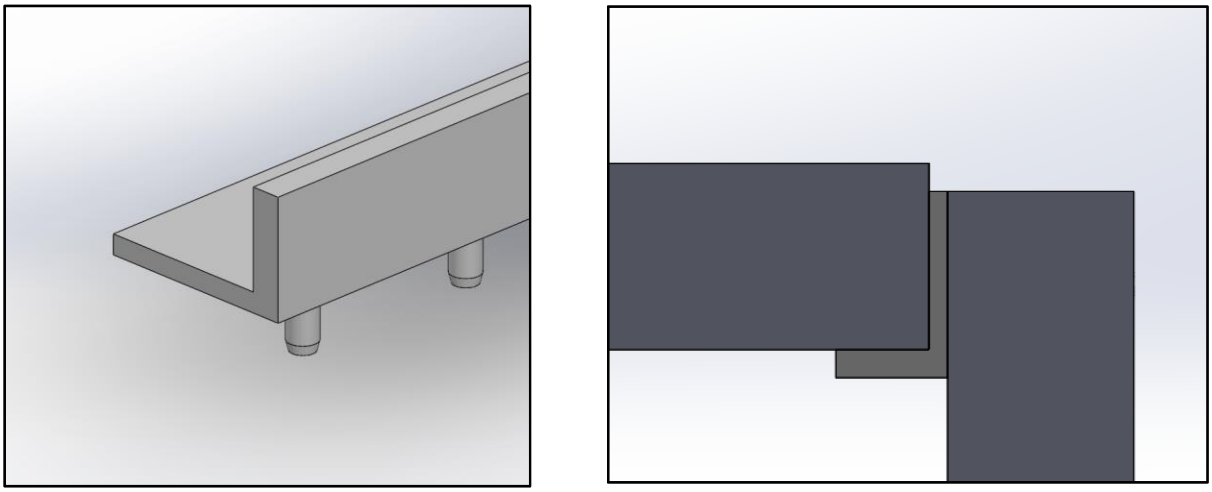


Image 73: Special union design

As mentioned, what you want to achieve with this accessory is that the user can install drawers to your liking. Therefore, despite having ruled out the horizontal connection to solve the set of unions in the study shelf, for this complement it was felt necessary to use horizontal I connection. The number of blocks is 30.

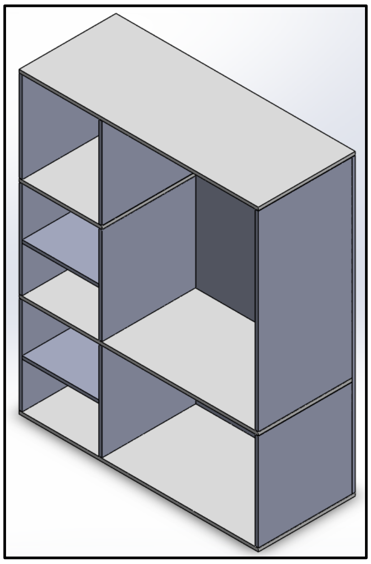


Image 74: View of furniture with two drawers connected with a continuous module of blocks

SIMULATION

The elements used in the simulation are the following:

- 1 wood plank (lower plank) of 1010x600x20mm
- 1 wood plank (upper plank) de 966x600x20mm
- 2 wood planks (side planks) de 620x600x20mm
- Module of 30 blocks

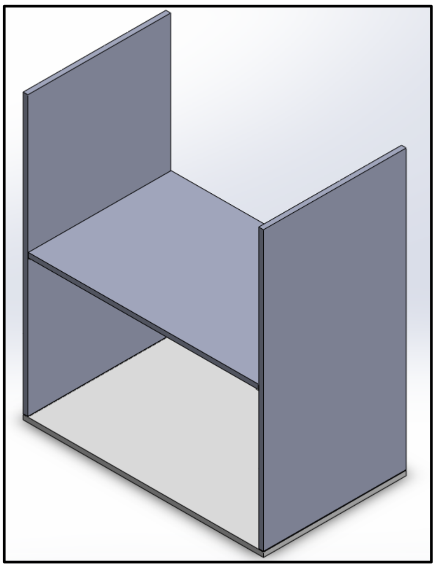


Image 75: Assembled elements for simulation

In order to simplify the simulation, 2 symmetrical cuts were made to reduce the number of degrees of freedom.

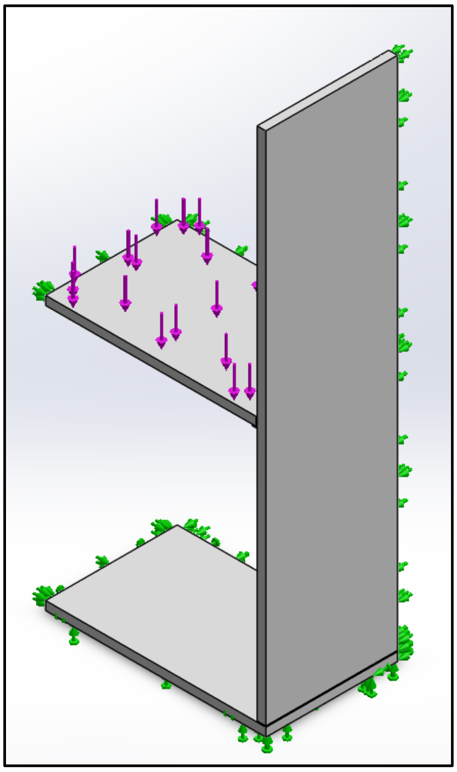
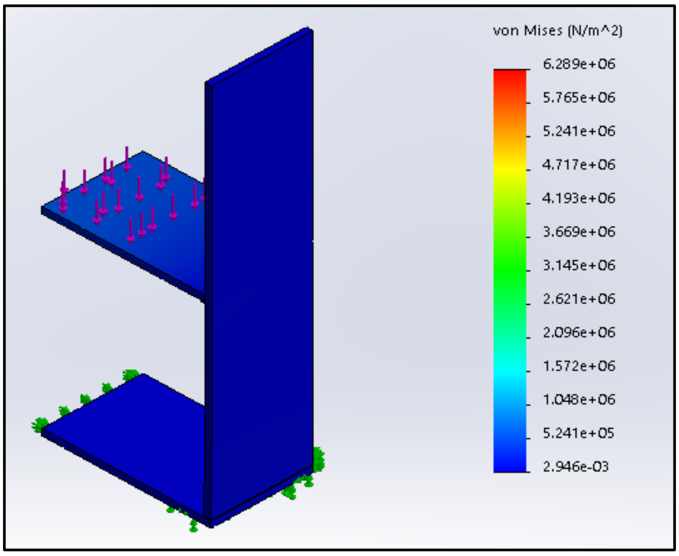
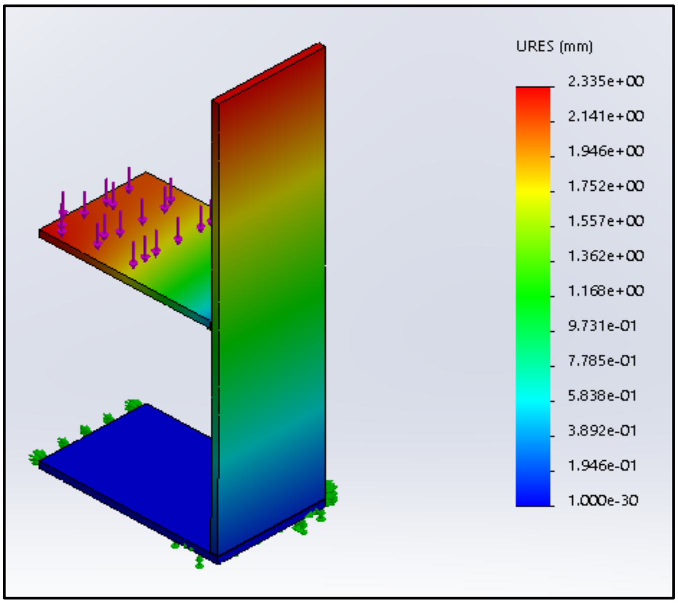
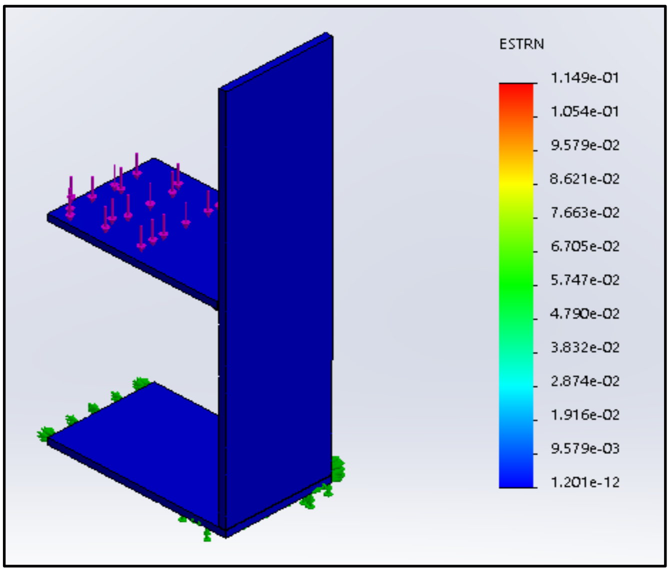


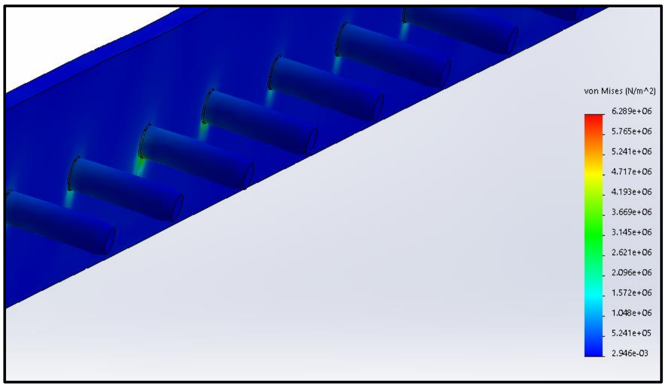
Image 76: Simulation conditions

Below are the images of the simulation made for this type of union:









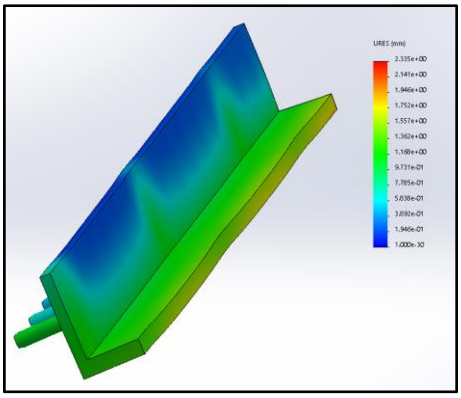


Image 77: Results of simulations

As for the stress of Von Mises, the maximum is at the base of the piuses. This value, however, is not alarming because it is less than the elastic limit of the material.

As for the displacements, the design is very good because the board has a maximum displacement of 2,335 mm. Blocks, on the other hand, suffer a very small displacement.

Therefore, it has been seen that this complement meets the mechanical conditions and therefore the user can use it freely.

5.4. Final design

The main objective of the project is to find the optimal number of blocks that the furniture needs and what is the optimal diameter.

Once the simulations have been carried out, the conclusion is that the optimum number of blocks for the model is 3 and that the optimum diameter of the blocks is 3 mm.

To obtain what was the optimum frequency for the blocks, there were 10 simulations to see how the study model varies. These are specified in the point 5.3.4.2.

To obtain the optimum diameter of the blocks, we looked for what were the most common drill diameters to make the holes and it was seen that they were 2-3-4 mm. It was decided that the best thing to start the simulations would be to start with the 2 mm drill bit and if, doing the simulations with different pumps frequencies worked, the diameter would be valid and if not, the diameter of the blocks would be increased and I would repeat the simulations again.

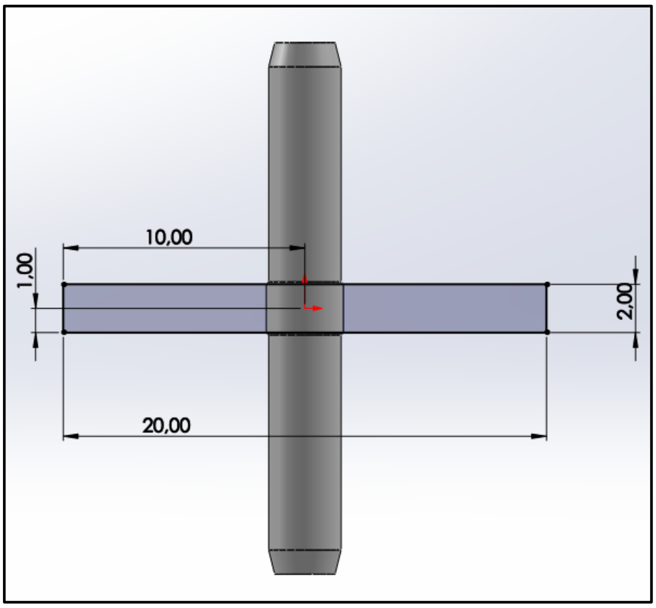
But, in a more exhaustive study of the operation of 3D printing machines, it has been found that the ideal minimum thickness for a piece is 2mm and that is why simulations have begun with a diameter of 3mm. If the diameter of 2 mm had been taken, there could have been errors when printing the blocks.

Once you have the optimum measures, there are four different models of modules: one to hold the right side of the furniture, another to hold the left side, another to hold the central part of the furniture and and the last one to hold the back of it.

Here is how to explain the details of the final design. It should be noted that the plans with the specifications of the blocks are in the annex and that as already stated, the diameter is 3mm.

Central module of blocks:

In the following images, we can see the profile that has the pit and its positioning. It is symmetrical, it has a total length of 600mm and the block has a length of 10mm.



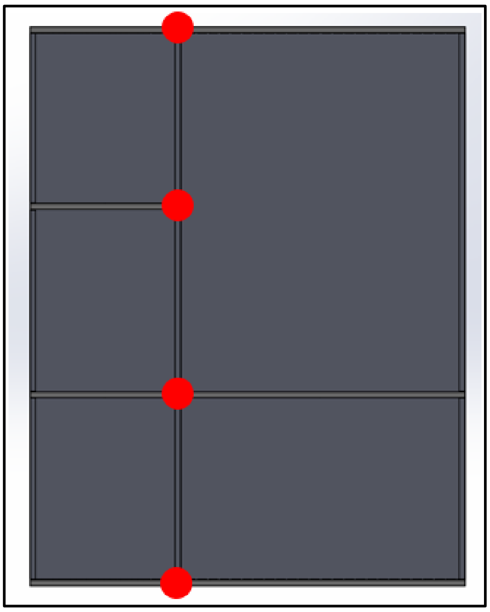
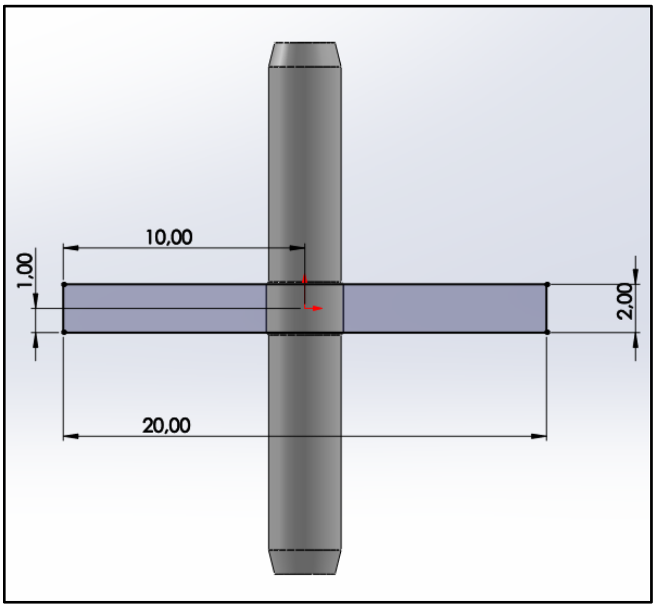


Image 78: Side view of the module (1)

Back module of blocks:

In the following images, we can see the profile that has the pit and its positioning. It is symmetrical, it has a total length of 1530mm and the block has a length of 10mm.



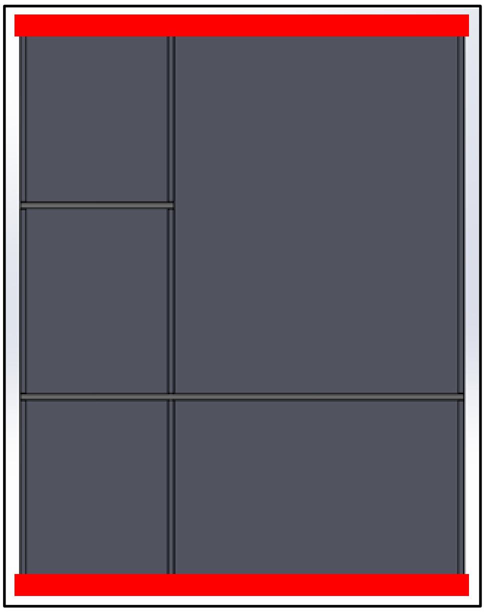
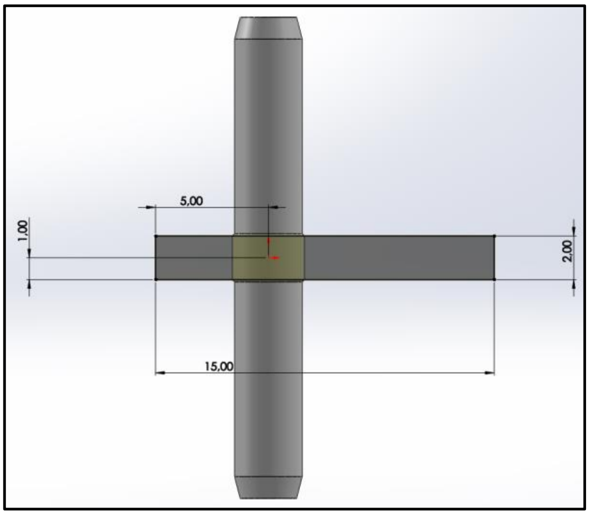


Image 79: Side view of the module (2)

Left module of block:

In the following images, we can see the profile that has the pit and its positioning. It is not symmetrical, it has a total length of 60mm and the block has a length of 10mm.



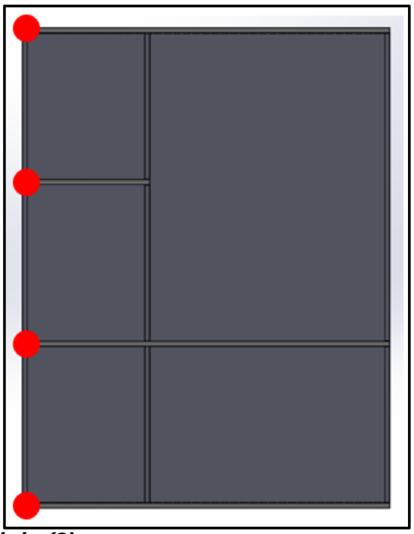


Image 80: Side view of the module (3)

Right module of blocks:

In the following images, we can see the profile that has the pit and its positioning. It is not symmetrical, it has a total length of 600mm and the beam has a length of 10mm.

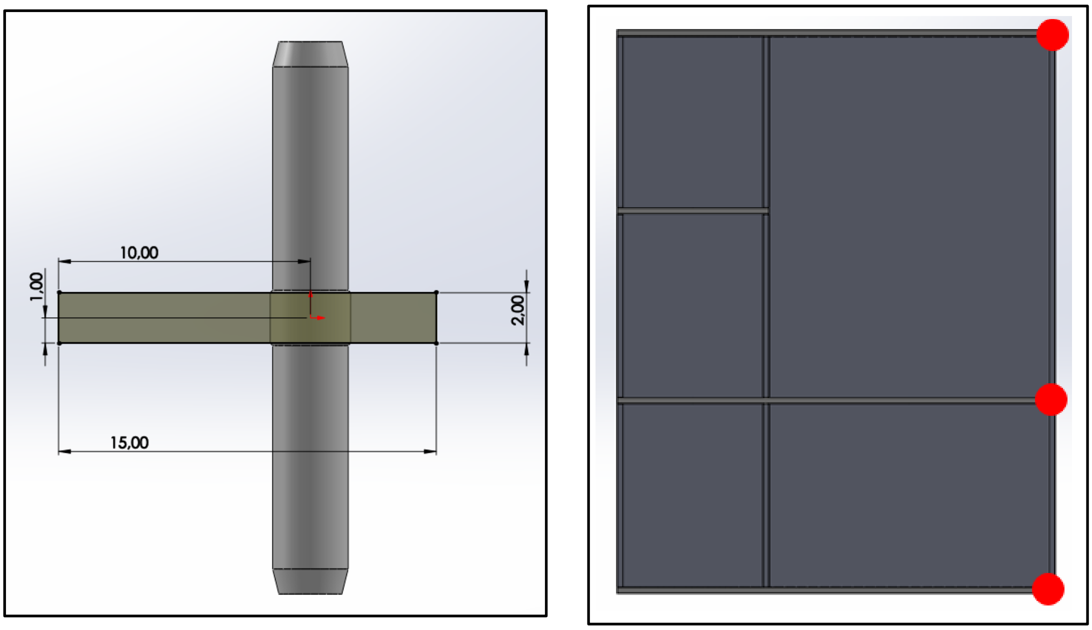


Image 81: Side view of the module (4)

6. Manufacturing

6.1 Manufacturing process

A manufacturing process is the set of operations necessary to modify the characteristics of raw materials. These characteristics can be of a very varied nature such as shape, density, resistance, size or even aesthetics. In order to obtain a specific product, many individual operations will be necessary so that, depending on the observation scale, the process can be called both the set of operations from the extraction of the necessary natural resources to their sale, to those made in a workplace with a particular machine or tool. The production, the industrial transformation, the distribution, commercialization and consumption are the stages of any productive process. This project aims to focus only on production. And in some way also in the consumption, which would be to be the assembly of the 'bought product'.

In fact, the manufacturing process of this project aims to be as simple as possible. It is one of the objectives of this one.

The two main raw materials will be the plastic powder to print the modules, and the wood.

In this section, it is intended to make a detailed study of the 3D printing technology (by means of which the user obtains the unions) and all the elements that intervene in the assembly of the proposed shelf. (templates, mounting manual, drill bits ...)

6.1.1 3D Printing technology

Although we still refer to 3D printing as a technology of the future, the truth is that there are a lot of companies and sectors that have already incorporated this technology into their production. The aerospace sector, of prototypes, in architecture, in the automotive sector, in the medical sector ...

Despite being an emerging market, it is worth pointing out that this technology has been developing for 30 years. Having said that, it should be noted that in fact, the last 4 years have been, in comparison, of much more growth than the previous ones. As a general note of the current economic situation of this technology, we can say that the last year closes having experienced a turning point that has proved decisive so that the 3D printing sector starts to make its first steps firmly for its definitive implementation. This means that this is a market in which each day counts, but that is still in a rather premature phase. There are nowadays a large group of companies that make impressions with many types of metals, for example the automotive sector, or medical, but there is still much to discover and improve.

The objectives are:

- Discover the general advantages of this technology, as well as the challenges that need to be overcomed for its improvement.
- Analyze the advantages and disadvantages of each current prototype manufacturing technology.
- Make a comparison of cost between some of the technologies explained.
- List the parameters to be considered in order to evaluate any prototype / 3D technology.

- General advantages

Here are the main advantages:

- CAD-to-Part: AM allows a 3D CAD drawing of a component or shape to be converted directly into a physical part.
- Freedom of Creation (FOC)
- Design for Customisation: Using AM (*) allows users to generate parts with greater customisation, with no additional manufacturing costs, such as extra tooling costs.
- Design for Function: AM manufacturing allows the user to design for function rather than for manufacture, for example allowing internal features that would be impossible to produce using conventional manufacturing techniques.
- Design for Light-weighting: Novel design and flexible manufacturing enable the production of lightweight structures. For example, parts can be made with hollow or complex lattice structures which retain structural strength but with reduced weight
- Near Net and Net Shape Manufacturing: AM enables the direct production of a component to their final (net) shape or with minimal need for additional process steps.
- Material Utilisation: AM techniques have the potential to approach zero waste regarding material utilisation. Any scrap powder generated can also be converted into new powder, ready for use again
- Reduced Time-to Market: While part forming using AM techniques can be slower than traditional manufacturing steps, the ability to consolidate several machining steps into a single manufacturing step, will dramatically reduce overall manufacturing time.

Image 82: Example of object obtained with 3D printing

- General challenges

Challenges as for productivity:

- Increase build-speed, possibly through new approaches to scanning or sources of energy.
- Decrease the time to create each layer, the overall time between layers, and start-up and shut-down time.
- Support higher volume production, possibly through enabling batch consistency and methodologies for consistent materials supply.
- Develop methodologies for measurement of AM products.
- The development of new/advanced AM machines e.g. machines with multiple lasers.

As per the process stability:

- Increase material processability, quality and performance.
- Develop methodologies for 'Right first time' processing
- Increase control of process tolerances.
- Develop tools for better temperature management during processing.
- Improve surface finish of processed parts.
- Improve geometrical stability.

Image 83: Example of object obtained with 3D printing

- Improve process control and monitoring.
- Analyse energy consumption and development of methodologies for its reduction.
- Further develop lasers with improved efficiency and control.
- Develop multi-material manufacturing for AM technologies.
- Reduce residual stresses.
- Increase software utilisation.

- Analyse stability of the AM process in order to make improvements to AM systems that will allow production components to be produced with required properties.

As per the materials used:

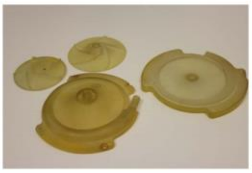
- Develop AM materials performance, static and fatigue, to enable a similar demonstrable performance level of cast and wrought material.
- Develop materials' consistency and repeatability e.g. fixing process parameters.
- Interchange-ability of process parameters between different AM machines.

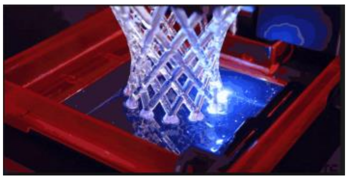
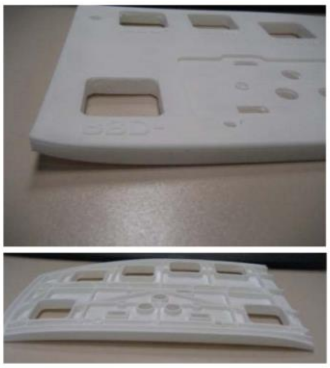
Image 84: Example of object obtained with 3D printing

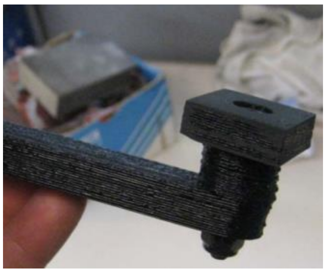
- Analyse material properties of different materials and multimaterials using AM techniques, including their validation.
- Identification of new semi-crystalline and amorphous polymers suited to different AM mechanisms.
- Analyse and develop of new materials for AM processing e.g. biomaterials, superconductors and new magnetic materials, high performance metal alloys, ultra-high temperature ceramic composites, metalorganic frameworks, new nano-particulate and nano-fibre materials.

● Analysing each 3D technology

Technology	Advantages	Inconveniences	Pics/Comments

3D printers with plaster and similars	-Office equipment. Lower cost compared to systems that allow technical prototypes. - Possibility of making pieces with color. - Ideal for concept stages.	Prototypes of limited precision and rough surface finishes. - Non-resistant materials: compacted plaster that must be infiltrated after making. - It is not used to test products, often limited to educational use or decorative objects	
Lom printers (paper)	-The same as those of plaster: lower cost compared to systems that allow technical prototypes, possibility of making pieces with color, ideal for stages of concept. - More resistance than plaster pieces. - Possibility of use for boxes to compact sand by smelting.	- Little implementation - Limited to use of concept or educational, it is necessary to varnish if they should get wet.	Very few companies in the sector develop / use this technology.
Stereolithography with liquid downwind and uv laser	- Surface finish. Possibility of transparent pieces. - Can be used for productive processes: model for silicone molds, or for "lost wax". - Depending on the size of the cuba, it is a technology that allows to make many pieces and	- Handling of uncoated resins: allergies - Fragility of the material if it is subject to effort - Price of the raw material (€ 185 / liter)	 

	more.		
Injection of resin (photopolymer)	Do not require supports, the pieces may be more complex. - Possibility of multimaterial parts, including elastomeric resins. - Easy to handle pieces and prepare the machine.	Expensive technology: the equipment must always be working, because it consumes resin to keep heads open. - Fragility of the material if it is put under effort	
VAT PHOTOPOLYMER	- Depending on the projection system of the image (UV laser) you can achieve unmatched precision. - Simplicity of DLP / LCD technology. There is no tank (car) or injectors (maintenance). - Undertake in progress: multitude of DIY developments.	Limited to a material. - Pieces of limited size, which are manufactured with supports. - Fragility of the material if it is put under effort.	
SELECTIVE LASER MIXING / FUSION (SLS / SLM)	- Technical prototype and possible use as a final product: materials similar to those of products, including metallic (PA, PC, stainless steel ...). It is the first technology that has opened the door to the additive manufacturing with metals. - Great	-Expensive technologies, industrial plant equipment with the need for internal atmospheres, filtering, security ... - Expensive materials, vendor monopolies.	

	productivity		
FFF TECNOLOGIES	- Materials similar to those of the products: ABS, PA, PC ... Few other technologies can say the same. -Cost of technology have reduced, causing the appearance of many DIY printers. The material is also cheaper.	- Need for supports in certain areas - The wire deposition requires exhaustive control of the process to avoid the fragility in the Z direction. - Slow process, and inaccurate and rough finishing. If you want speed (thick thread) the accuracy is sacrificed.	
3D WAX PRINTERS	- Specialized in the manufacture of models for digital processes: jewelry, orthodontics. - Office equipment and clean workshops (jewelers and medicine)	-Very fragile prototypes. DLP technologies, suitable for lost and more resistant wax models, have grown a lot. - Work with temperature: maintenance by thermal fatigue of the heads.	They usually have excellent surface finishes.
SILICONE MOLDS	- They allow to make a very quick preserie of final products at a more competitive price than any other technology. - Polyurethane allows to simulate the technical	- Handmade process, based on the know-how of the technicians. - Limited life of the mold for 25 pieces and 6 months. - The design of the	

	characteristics of any plastic injection	component is different from the one of the injection mold	
IDEAL	- Multimaterial. From thermoplastic technical material (ABS, PP, PA, PC) valid as final material such as SLS, to elastomeric and soft materials such as TPE / TPU / silicone / hydrogels ... Different densities and hardnesses. Multicolored - Inert materials, chemical "smart". - Workshop equipment but as simple as desktop machines. - Non-rough finish: thinner powder or liquid starting material. - It is not necessary that many prototypes can be made at the same time but the speed of layers is fast. - Source of low cost energy, no gas to inertify. - Good recyclability.		Finally, we wanted to add a technology that does not exist in the market. It shows properties that would be ideal for the printer.

Table 6: Different techniques of 3D printing

- Price comparison of some technologies

Below is a small comparative study of some of the technologies mentioned in the previous point.

To do this, a component of: Mass volume (*) of 18.17 cm3 and dimensions in mm: 90x90x50.

PROTOTYPE IN LIQUID STEREOLITHOGRAPHY

Material price: 185 €/kg

Machine time: 10h

Final price: 165€

Delivery deadline: 2-3 days

Supports must be processed

PROTOTYPE IN PA+GF (SLS)

Price material: 60 €/kg

Final price: 118 €

50% of the powder can be recycled

PROTOTYPE IN FFF of Open Code

Material price:

- Basic PLA 3mm: 19€/kg
- ABS Premium 3mm: 27€/Kg

Delivery deadline: 1 day.

Price (ETSEIB Fabr. Digital): 8,25 €

PROTOTYPE IN PA (SLS)

Price material: 66 €/kg

Machine time: 5h

Final price: 75€

Delivery deadline: 1-2 days

70% of the powder can be recycled

Density 1gr/cm^3

No supports, pieces can be piled up

PROTOTYPE IN MELTED WAX:

Price of the wax: 160 €/kg

Machine time: 15h

Melting price: depends on the metal

Delivery deadline: 8-10 days

The matrix is destroyed

Final price: 201€ (model) + 300€ (matrix +melting) = 510 €

PROTOTYPE IN POLYURETHANE

SLA model is needed, and then the silicone mold is done (MS)

Silicone price: 22€/Kg

Resin price PU: 32€/Kg

Delivery: 8-10 days

Model price SLA + MS: 165€ + 360€ =525€ (Considering 25 pieces and 21€ of amortization

Total unitary cost: 56€

Table 7: Cost of prototipes with differents process

- Parameters to guide the selection of a technology:

- Economical: price of machines, price of materials, annual cost of maintenance, amortization cost, average cost of the prototype.
- Associated with the prototype: material, size, resistance, rigidity, dimensional stability, durability in time, toxicity, surface finish.
- Associated with the productive process: ease of operation and usability for non-technical people, finishing process, execution time, possibility of execution of "impossible" designs, design stage in which its application is optimal, job security and environmental
- Other parameters: location of the equipment (office or plant), dissemination of technology, security of the manufacturer / distributor.

Below is an example parameter associated with the prototype: the resistance. The graphic suggests a printing technology for each type of material.

Waxes – *Invision HD, Solidscape*
Adhesive bonded polymers powders – *Z-Corp*
Solvent 'fused' polymers PMMA - *Voxeljet*
Photocurable monomer – polymers such as epoxies', acrylic's,
Oxetane's, nano-filed resins – *3D systems Stereolithography, Objet Polyjet, Nextfactory Digiwax, EnvisionTEC Perfactory*
Heat sintered Polymers such as Nylons, GF nylons and composite filed nylons – *3D systems Sinterstation, EOS EOSINT P, Can-Do-Run*
Heat fused polymers such as ABS *– Stratasys FDM*
Polymer bonded sheet systems – *3D Systems Invision LD, Solidimension, Graphtec*
Aluminium bonded sheet – *Soligen Ultrasonic compaction*
Semi solid sintered tool steels *– 3D systems Laser form, ProMetal*
Titanium's, Cobalt Chrome and aerospace alloys – *MCP SLM, EOSINT M, Phenix, Arcam EBM*
Tool steels– *Trumpf DMD / Concept Laser Laser Cusing*

Table 8: Printing technology for each material

You can see clearly how resins are the most fragile, and on the other hand those of greater durability are titanium, cobalt and steels. For each one, a different print technology is suggested.

6.2 Assembly

En aquest apartat es pretén detallar en què consisteix el muntatge de la prestatgeria. Quins elements calen, com es farà per fer-hi forats als taulons de fusta, quin tipus de broca s'ha d'utilitzar, quines limitacions té el muntatge pel fet d'utilitzar les unions dissenyades i quin tipus de tecnologia 3D es recomana per imprimir les unions i les plantilles

6.2.1 Necessary elements for the assembly

As for the wooden planks, as already mentioned in the selection section of material, the wood used is just a suggestion. You can use one of better properties or aesthetics. The dimensions of the wood planks are specified in the section of the choice of furniture.

As for the blocks, they are described in point 5.4 Final design. Obtaining these is very simple. In the hypothetical case that this project was commercialized, the user would lower the plans in a 3D library with a STL format and then, print it in 3D with your 3d printer.

This project also has designed three applications, inspired by the union in I of the project, that can serve as accessories for the shelf.

6.2.2 Templates

During the development of this project, it has been necessary to design something that was used to facilitate the making of holes on the wooden planks. Although an optimum blade arrangement frequency has been found, the fact that the user drill holes with a drill can cause mounting errors. For this reason, it has been designed to design templates, which will also have their corresponding plans and can be printed in 3D, to make the hole simpler to the fullest possible.

The templates for the module of blocks are as follows:

-Central, left and right module of pius:

This template can be used with the central, left and right module of blocks. This is because the only difference between them are that the central are symmetric and the left and right are not symmetric. The position of the holes are the same in all three cases, in the middle of the wood plank and at the same distance. This is why with this template, you can do all the holes for the central, left and right part of the furniture. This template has three holes.

Then, you can see a image of the template for this holes:

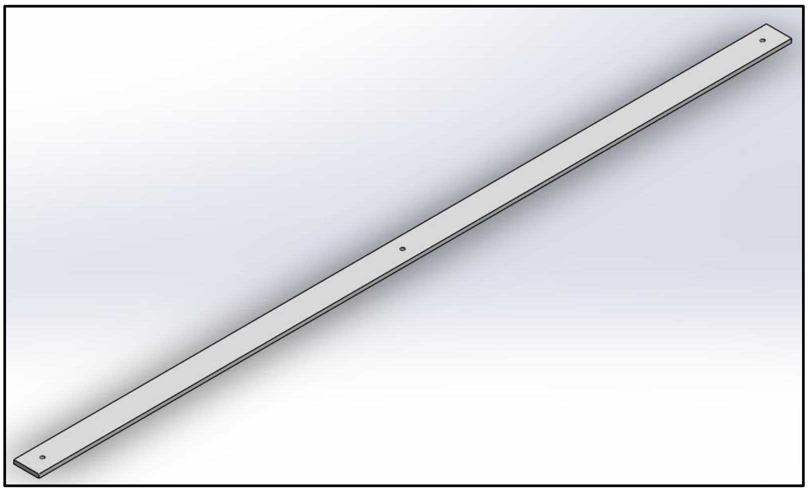


Image 85: Templates of the central, right and left module of blocks

Measures: 20x600x3mm

-Back module of blocks:

This template is similar than the previous one but with the difference that this one is longer than the other one. This template you can only use it in the back of the furniture. This template has three holes.

Then, you can see a image of the template for this holes:

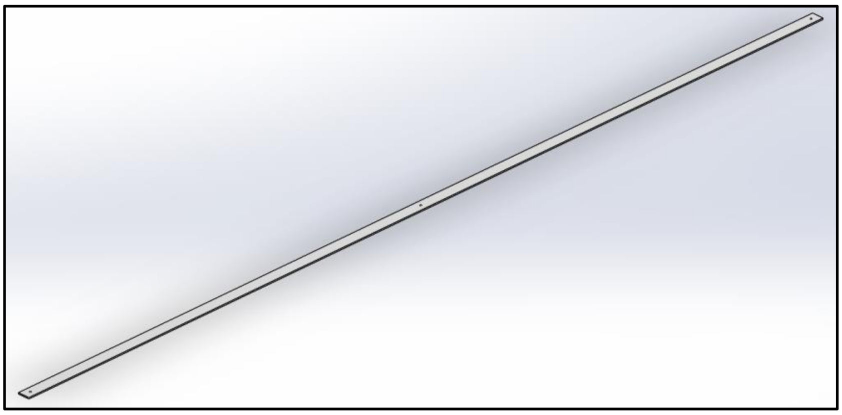


Image 86: Templates of the back module of blocks

Measures: 20x1530x3mm

Now, the templates for applications will be explained.

-Continuous union:

This template, together with the bar, are the different ones. The reason is because this application has an horizontal connexion and need more blocks. The template has thirty holes.

Then, you can see a image of the template for this holes:

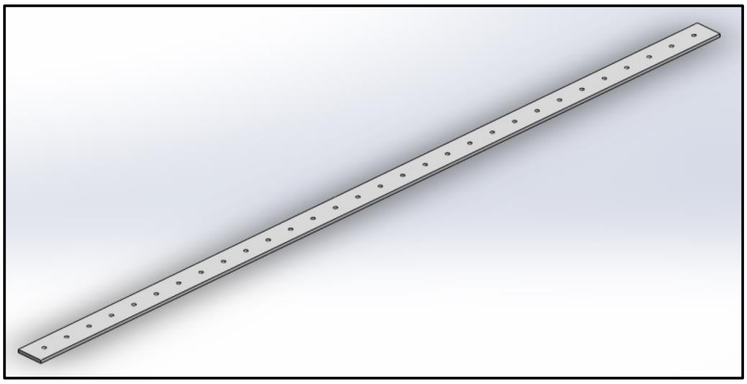


Image 87: Templates of the continuous module of blocks

Measures: 20x600x3mm

-Bar

The idea of this template is to place it on the sideboards that will support the bar-hanger and make the corresponding holes. This template is the most important of all because the holes are not on a straight line like the others. This template has ten holes.

Then, you can see a image of the template for this holes:

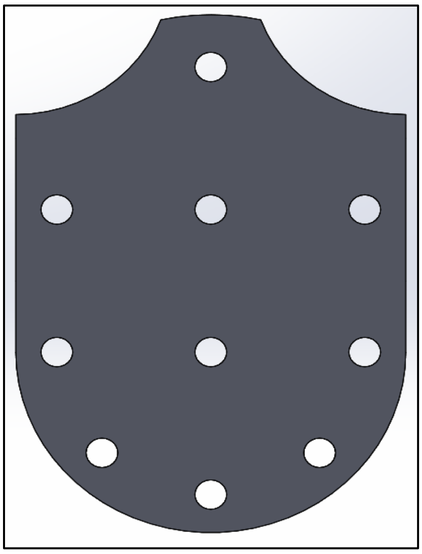


Image 88: Templates of the circular module of blocks

6.2.3 Drills

If you wanted to assemble the furniture, you should not underestimate the manufacturing error when dealing with wood. Assuming that the different parts of the furniture were already in place with their respective measurements, we would have to proceed to make the holes, using the templates, for their subsequent fitting with the plastic pieces designed

To make the holes, a drill is used. However, a quality drill will not do a good job unless the correct bit is available. Therefore, the first criterion to take into account when choosing the right accessory is to know the material on which it is going to be drilled. Depending on the material, we will choose a specific drill bit. In our case, the following:

Wood drills:

Drill bits for wood and derivatives are usually made with chrome vanadium (CV). Like the bits for metal, they are characterized by their cutting edges, which are those that open the fibers of the material, but they differ in that they usually have a centering point, very pronounced, to dig into the wood before drilling. They usually have the elongated propeller, to easily dislodge the wood chips

The right bit will depend on the type of wood (soft or hard) and the diameter that is needed. Its use is exclusively for wood. It is advisable to use a drill without percussion.

The sizes:

Drill bits can be found from 1 mm in diameter (for precision work) up to 25 mm, for big works.

Normally the diameter also determines the length of the bit. At smaller diameters, shorter bits and, therefore, less depth of cut.

In our case, we will make holes with a diameter of 3 mm. The picture shows some standard sizes of drill bits.

Image 89: Different types of drills

6. Materials selection

This section is very important since the whole study depends on the material that all the elements of the piece of furniture are composed. Among the elements that we can identify in our model are the planks that make up the furniture and the joints that unite these woods.

The final proposal is oriented to the DIY for this reason, the planks are prefered to be of some type of wood that facilitates the work. As the proposal is to obtain the unions by means of 3D technology, some type of plastic will be used for sure.

As for the wood, we want it to be resistant, of a reasonable hardness and easy to work and with simple maintenance.

For plastic we want it to be resistant, with a high Young Modulus and recyclable.

Next, a brief explanation will be made explaining the properties of the materials that are candidates to be the chosen for the planks. It is to say that the materials used in the simulations are generally worse than the ones proposed as it follows. It is in hands of the user to choose one material or another. These materials are: oak, chestnut tree, mahogany, teak, pine and cherry tree.

Properties of the oak:

·Resistant

·Great hardness

·High quality

·Yellowish brown color although there are many different species and each one with a particular hue of color.

·Long useful life

·Easy to work

·Good finish with paint and/or varnishes

·May have cracks if drying is not correct

·Average density (12% relative humidity): 720 kg/m^3

·Flexion resistance: 950 kg/cm^2

·Compression resistance: 570 kg/cm^2

·Traction resistance: 980 kg/cm^2

·Elastic module: 115000 kg/cm^2

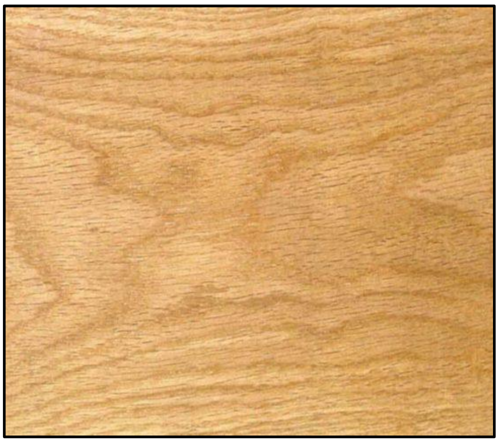


Image 90: Color of the oak

The term oak is used to refer to many tree species of the genus Quercus, native to the northern hemisphere.

The oak is one of the most known trees in the northern hemisphere both for its longevity, up to 200 years, and for its appreciated wood.

Price: 1200 €/m^3

Properties of the chestnut tree:

·High resistance

·Great hardness

·Good quality

·Yellowish brown color

·Very long useful life

·Hard to work: you have to be careful when drilling as it usually opens. Pre-drills are advised

·Good behavior before finished and glued.

·Easy maintenance

·Average density (12% relative humidity): 590 kg/m^3

·Flexion resistance: 720 kg/cm^2

·Compression resistance: 470 kg/cm^2

·Traction resistance: 1270 kg/cm^2

·Elastic module: 95000 kg/cm^2

Image 91: Color of the chestnut tree

Castanea is a genus of plants of the fagáceas family, native to the temperate regions of the northern hemisphere, commonly known as chestnut trees.

The chestnut tree is a tree of great longevity and majestic bearing.

Precio: 2100 €/m^3

Properties of the mahogany:

·Resistant to bumps and scratches

·Medium hardness

·Very high quality

·Red and brown tonalities

·Long useful life

·Easy to work

·Little impregnability

·Need for treatments to stay in good condition

·Average density (12% relative humidity): 560 kg/m^3

·Flexion resistance: 850 kg/cm^2

·Compression resistance: 4+0 kg/cm^2

·Traction resistance: 1270 kg/cm^2

·Elastic module: 90000 kg/cm^2

Image 92: Color of the mahogany

Mahogany is a characteristic reddish wood, very appreciated for the manufacture of high quality furniture. It comes from three species of trees in the intertropical zone of the American continent.

Mahogany is easy to work while resistant to parasites.

Precio: 3800 €/m^3

Properties of the teak:

·Great resistance to extreme climates

·Great hardness

·Very good quality

·Golden brown color

·Very long useful life

·Easy to work

·Little customizable

·Does not need much care

·Average density (12% relative humidity): 450 kg/m^3

·Flexion resistance: 1020 kg/cm^2

·Compression resistance: 630 kg/cm^2

·Traction resistance: 850 kg/cm^2

·Elastic module: 110000 kg/cm^2

Image 93: Color of the teak

It is native to India, Burma, Laos and Thailand.

It is a leafy tree of the Verbenaceae family that reaches up to 30 m in height. Its appearance becomes more beautiful over the years and has the ability to not be damaged when it comes into contact with metals.

Price: 1000 €/m^3

Properties of the pine:

·Average resistance

·Little hardness

·Medium quality

·Pale yellow color

·Average useful life

·Easy to work

·Customizable, great variety of colors thanks to the treatments that wood can receive

·Simple maintenance

·Average density (12% relative humidity): 540 kg/m³

·Flexion resistance: 1057 kg/cm^2

·Compression resistance: 406 kg/cm^2

·Traction resistance: 1020 kg/cm^2

·Elastic module: 94000 kg/cm^2

The pines are native to the northern hemisphere, with only one species found in southern Ecuador.

The fruit of the pine, the pineapple, was also used in ceremonies of the cult of Bacchus. Sometimes, Silvano is represented with a branch of pine in his right hand.

Precio: 2100 €/m³

Image 94: Color of the pine

Properties of the cherry tree:

·High resistance

·High hardness

·Good quality

·Red color

·Long useful life

·Easy to work

·Very impregnability

·Easy maintenance

·Average density (12% relative humidity): 580 kg/m^3

·Flexion resistance: 850 kg/cm^2

·Compression resistance: 480 kg/cm^2

·Traction resistance: 990 kg/cm^2

·Elastic module: 105000 kg/cm^2

Image 95: Color of the cherry tree

They are from Europe and Western Asia.

The cherry tree wood is hard and reddish, and is used to make furniture.

Precio: 1200 €/m^3

-Final decision:

In order to make a better decision, a summary table was done to be able to more easily assess the properties of each material and thus help the user in the election of the material. Next, we attach the table:

Properties/wood	**Oak**	**Chestnut tree**	**Mahogany**	**Teak**	**Pine**	**Cherry tree**
Resistance	High	High	High	High	Medium	High
Hardness	High	High	High	High	Low	High
Quality	High	High	High	High	Medium	High
Color	Brown	Brown	Red	Brown	Yellow	Red
Lifespan	Large	Large	Large	Large	Medium	Large
Easy to work	Yes	No	Yes	Yes	Yes	Yes
Customizable	Yes	Yes	No	No	Yes	Yes
Maintenance	Normal	Easy	Difficult	Easy	Easy	Easy
Average density (kg/m^3)	720	590	560	450	540	580
Flexion resistance (kg/cm^2)	950	720	850	1020	1057	850
Compression resistance (kg/cm^2)	570	470	480	630	406	480

Traction resistance (kg/cm^2)	980	1270	1270	850	1020	990
Elastic module (kg/cm^2)	115000	95000	90000	110000	94000	105000
Price (€/m^3)	1200	2100	3800	1000	2100	1200

Table 9: Summary table of the different materials and characteristics

Among the most popular 3D printing materials for fusion deposition are PLA (polylactic acid) and ABS (Acrylonitrile Butadiene Styrene).

Properties of the ABS:

·Thermoplastic derived from petroleum

·Hard

·Good resistance to fatigue

·Resistant to great impacts

·Rigidity

·Mechanical resistance

·It can be machined, polished, polished, drilled, painted, etc.

·During the extrusion there is a slight smell of burned plastic and some toxic vapors

·It is not a biodegradable material

·Recyclable material

·With regard to print quality, this material tends to bend and the piece can undergo a slight deformation at the bottom

·Density: 1070 kg/m^3

·Price: 20-35 €/kg

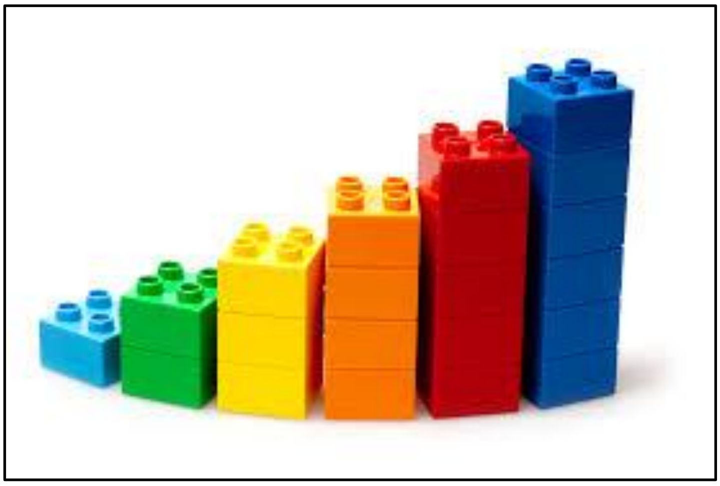


Image 96: Typical object make it with ABS

Properties of the PLA:

·Plastic of vegetable origin (corn)

·Brittle

·Biodegradable material

·It does not emit harmful gases

·Shorter lifespan

·The processes of machining, drilling, painting, etc. They are much more complicated than ABS

·During printing this material suffers fewer deformations and allows you to print much fine details

·Density: 1250 kg/m^3

·Price: 20-35 €/kg

mage 97: Typical object make it with PLA

-Final decision:

Both materials are valid to perform the function, but considering the use that will be given to these elements, it seems more accurate to choose the ABS. The main reason why the ABS is chosen from the PLA is because of the ease that it offers in the post process. The modules want to be able to paint, cut ... alter their appearance as easily as the user wishes.

Once given the final proposals for the materials to be used in the furniture, it is recalled that these are recommendations and the user can modify it according to their need as long as the new materials have the same or better properties to the recommended materials as they can affect the final result.

8. Budget

At this point the cost of the furniture to be manufactured will be discussed but before that, it is important to talk first about the project.

This project aims to the user who wants to make the furniture and can download the file of the unions and the templates of the Internet and can print them without the need of a third person. This is important because in this section, we do not include patent, engineer, transport or logistics costs, since the idea is to do it yourself (DIY). Neither will be taken into account the cost of the drill and the drill bits since this cost is irrelevant (perhaps the user already has a drill with the necessary drill bits).

Next, we will do a summary table in which you can see the number of pieces needed for each type, the total volume of each piece, its cost per volume and the total cost of each type of piece. In the end, a total sum will be done to see the total cost of the manufacture of the furniture.

Pieces/Details	**Units (u)**	**Volume/u**	**Total volume**	**Price/volume**	**Total price**
Drawer+Slider	1	0.0183 m^3	0.0183 m^3	1000 €/m^3	18.30 €
Drawer	1	0.00635 m^3	0.00635 m^3	1000 €/m^3	6.35 €
Side1	2	0.00696m^3	0.01392 m^3	1000 €/m^3	13.92 €
Side2	1	0.0147 m^3	0.0147 m^3	1000 €/m^3	14.70 €

Side6	5	0.00744 m³	0.0372 m³	1000 €/m³	37.20 €
Floor	1	0.0189 m³	0.0189 m³	1000 €/m³	18.90 €
Cover	1	0.0571 m³	0.0571 m³	1000 €/m³	57.10 €
Ceiling	1	0.0189 m³	0.0189 m³	1000 €/m³	18.90 €
Right union	4	$0.0183 \cdot 10^{-3}$m³	$0.0732 \cdot 10^{-3}$m³	29425€/m³	2.15 €
Center union	6	$0.0244 \cdot 10^{-3}$m³	$0.1464 \cdot 10^{-3}$m³	29425€/m³	4.31 €
Left union	6	$0.0183 \cdot 10^{-3}$m³	$0.1098 \cdot 10^{-3}$m³	29425€/m³	3.23 €
Back union	2	$0.0616 \cdot 10^{-3}$m³	$0.1232 \cdot 10^{-3}$m³	29425€/m³	3.63€
Template of 1510 mm	1	$0.0917 \cdot 10^{-3}$m³	$0.0917 \cdot 10^{-3}$m	29425€/m³	2.69
Template of 600 mm	1	$0.0359 \cdot 10^{-3}$m³	$0.0359 \cdot 10^{-3}$m³	29425€/m³	1.06
TOTAL	**33**	**-**	**0.1859 m³**	**-**	**202.44 €**

Table 10: Summary table with the cost to all the pieces of the furniture

The total cost of printing the pieces and buying the planks is 202.44 €.

In the previous budget only the furniture has been taken into account and not the accessories. Now the budget of the accessories is done:

Pieces/Details	**Units (u)**	**Volume/u**	**Total volume**	**Price/volume**	**Total price**
Continuous union	2	$0.0441 \cdot 10^{-3}$ m³	$0.0882 \cdot 10^{-3}$ m³	29425€/m³	2.59 €
Drawer	1	0.00635 m³	0.00635 m³	1000 €/m³	6.35 €

Continuous union template	1	0.0354· 10^{-3}m³	0.0354· 10^{-3}m³	29425€/m³	1.04 €
Bar	1	0,000706 m³	0.706· 10^{-3}m³	1000 €/m³	0.71 €
Bar union	2	0,0104· 10^{-3}m³	0.0103· 10^{-3}m³	29425€/m³	0,61 €
TOTAL	**12**	**-**	**0.0306 m³**	**-**	**11.30 €**

Table 11: Summary table with the cost to all the pieces of the applications for the furniture

The total cost for the applications is 11.30 €.

If you want to assemble all the furniture, the total price is **213.74 €.**

9. Conclusions

Once the project is finished, it it determined that it is possible to arrive to a solution proposal of the problem raised.

Modules that have been designed and evaluated allow the assembly of a piece of furniture without the need to use any kind of screw or similar element.

The project preceding this one focused on the design and validation of three union modules. In this one, the study has focused on one of them, analyzing it and optimizing it. With it, we have tried to solve all the unions of a piece of furniture in particular; a bookshelf

During the first phase, it is attempted to solve the unions with the horizontal connection, but this is ruled out by a more efficient one: the connection I in vertical.

In the same way, two additional elements for the shelf have been designed and validated. Both inspired by the model optimized in this project.

Regarding the objective of minimizing the final cost, it is believed to have been met. The final price that is detailed in the study of costs is relatively low in comparison to the offer that is in the market.

So the points that wanted to b studied on this project have been fulfilled:

- Easy building
- Minimizing final cost
- Manufacturing process and DIY
- Sustainable, recyclable or biodegradable materials
- Achieve a design that can have shelves, hangers and other accessories.

As mentioned, despite having reached a solution, the design that has been reached in this project can be complemented by possible modifications to it in order to work in more situations.

The result of this study is the start of a future project to be commercialized. The bases of the project, that are susceptible to changes in a justified and reasoned way, have been established.

10. Future projects proposals

In this project the union in I has been studied in depth. In addition, and following the same idea of not using screws, two applications for the furniture have been designed and simulated. This designs can most possibly be improved. In the same way, some new elements could be designed.

As it follows, several proposals of future projects are exposed:

- Considering the complementary elements that have been designed, it would be positive to study them in depth, and try to optimise their number of blocks.
- Adapt the modules in I studied to other types of furniture, ie. of different sizes.
- Do simulations considering a Horizontal force in order to guarantee the stability of the whole furniture.
- Complete a general simulation of the furniture with all the forces applied.
- Complete the design of a sliding door which has been somehow started in this project (see Annex)
- Create a Business Plan in order to prepare the Go-To-Market of this product

The design proposals that are made should follow the aesthetics, the design, of the already designed, so that it can create a collection of elements for the manufacture of furniture without screws.

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